OFFSHORE POWER SYSTEMS
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Jacksonville, Florida 32211

CERAMIC WELD BACKING EVALUATION

FINAL REFORT
JUNE 1980

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FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of The Society of Naval Architects and Marine Engineers and financed largely by government funds through a cost-sharing contract between the U.S. Maritime Administration and Bethlehem Steel Corporation. The effort of this project was directed to the development of improved methods and hardware applicable to shipyard welding in the U.S. shipyards.

Mr. W. C. Brayton and Mr. F. X. Wilfong of Bethlehem Steel Corporation were Program Managers, Mr. T. E. Bahlow of Offshore Power Systems (OPS) was Project Manager, and Mr. R. E. Cantrell and Mr. D. J. St. Pierre of OPS were the Principal Investigators.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of subcontract proposals.

FINAL REPORT
ON
CERAMIC WELD BACKING EVALUATION

OFFSHORE POWER SYSTEMS
JUNE 1980

I. ABSTRACT

Representative ceramic weld backing systems were evaluated with representative FCAW and SAW processes to determine their efficacy to produce second side weld contours not requiring subsequent back welding or preparation for inspection. Weldments were prepared and evaluated for soundness, toughness, bead shape, ceramic attaching methods and ceramic neutrality. Significant weldment soundness problems were identified for certain FCPW processes in certain positions. Changes in welding technique appear promising for control of these problems (though at some expense in bead shape) but further development in certain instances is required. Relatively minor bead shape problems were identified and corrected for FCAW. More significant bead shape problems were identified for submerged arc particularly in tandem applications. No other problems of potential significance were identified. Promising joint designs, parameters and techniques were identified for welding over ceramic backing. Recommendations for future development are made.

II. INTRODUCTION

One of the most costly and bothersome aspscts of the welding industry today is preparation of the weld second side for subsequent welding or inspection. Apart from the low deposition rate welding processes such as GTAW and GMAW short arc, to some degree, no others will consistently produce full penetration one side welds with a smooth, controlled back side contour. The problem is further aggravated by the latitudes in joint geometry historically encountered in a construction environment.

Over the years numerous hacking systems (flux containers, fiberglass tapes, flux covered tapes, ceramic tiles, copper shoes, etc.) have been introduced and endured with varying levels of success and adaptability. As yet, none have found general acceptance. Varies, of Holland, seems to have been the most dedicated and now markets a ceramic backing system complete with special filler material and power sources. Even though ceramic backing, per se, is not new, there is renewed interest and enthusiasm among domestic vendors. There is general agreement that if a backing system evolves prmitting full penetration one side welding with high deposition rate welding processes, is forgiving enough to absorb construction tolerances, is relatively easy to use, and is cost effective in a production environment; the welding industry will commence a new era of efficiency.

The objective of this program was to establish if ceramic tile backing and flux cored arc welding (FCAW) and submerged arc welding (SAW) butt welding applications could provide:

- o visually acceptable as-welded back side contours requiring no cosmetic grinding repair
- o volumetrically acceptaable weldments requiring no grinding and welding repair.

III. CERAMICS

The word "ceramics" covers a wide variety of products, all of which are made by forming followed by firing. Ceramics usually consist of oxides, such as silica (sand), alumina, magnesium oxide and iron oxide; carbonates, such as barium carbonate; compunds of oxides, such as steatite (soapstone), or cordierite; or non-oxidic Compunds, such as silicon carbide (Carborundum). These substances are either found in nature as minerals, or are prepared from other natural raw materials. In either case, the raw material contains certain impurities as well as the desired compound. These impurities are usually present in the final product and help determine its properties.

After the raw materials are mixed, they are often heated to a temperature at which any water of crystallization, or carbon dioxide from carbonates, is driven off (this process is called "calcining"). Other chemical reactions and a degree of sintering can occur during this process. After calcining, or in combination with the mixing if calcining is not required, the powder is generally ball milled to a fine grain size.

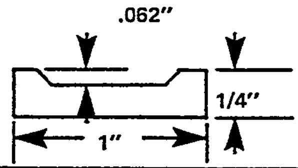
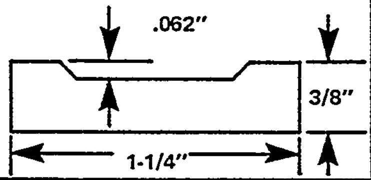
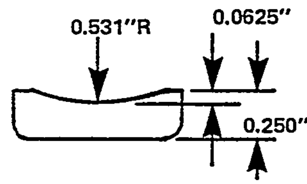
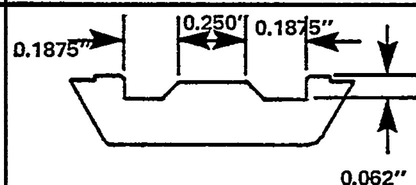
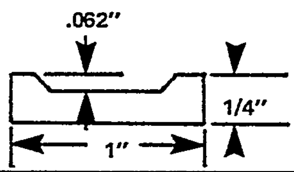
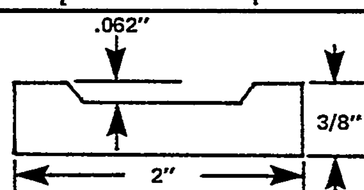
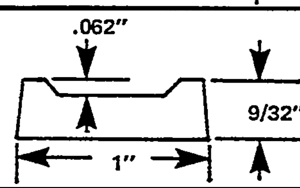
The powders are then given the desired shape by pressing in a mold, if necessary mixed with water and a "binder", an organic substance that makes the grains of powder adhere together. An important varient of pressing is "extrusion" in which the substance, made plastic with water and clay or an organic binder, is forced under pressure through a nozzle.

In the next stage (firing), the formed products are heated to between 1800 and 3600°F. The material undergoes further chemical changes and the grains which compose the powder fuse together. This process (sintering) can involve shrinkage of up to 30% possibly causing ceramic products even from the same mold to vary considerably in dimension and shape. Ceramics may be "sintered to density" where any pores left are closed ones and the density is at a maximum. In practice, however, all intermediate states from slightly baked powder containing continuous pore channels to the “sintered to density” state are used.

Ceramics are much used for their chemical resistance. In oxidic ceramics the oxygen is so firmly bound that it is only at very high temperatures, and in strongly reducing atomospheres, that reduction and hence break-up of the material can occur. Alumina, sillimanite, magnesia, zirconia, chromite, porcelain, and graphite are resistant to certain molten metals. If molten slag contacts the ceramic material, the nature of the slag (i.e., whether is contains an excess of base-forming or acid-forming oxides) must be considered. Ceramics are frequently used where resistance to attack from acids, bases and salt solutions is required.

Ceramics are often used because of their favorable properties at high temperatures and under oxidizing conditions. Their thermal conductivity is much lower than for metals (about 6%). Examples of heat resistant ceramic materials are alumina, chamotte, chromite, cordierite, forsterite, magnesia, porcelain, mullite, silica, zirconia, the non-oxidic silicon carbide (Carborundum) and graphite.

The ceramic weld backing systems evaluated in this report are identified in Table 3.1. The principle constituents are cordierite and steatite with differences among manufacturers probably due to differences in raw materials and/or processing cycles. The Varies ceramics were used with the Varies magnetic holding devices, steel trays which hold the ceramic tiles and in turn are held over the weld joint by magnets. The other brands of ceramic backing were held in place with aluminum adhesive tape.

MANUFACTURER	DESIGNATION	SUPPORT	DIMENSIONS	MATERIAL
KUDER	1CR-062	ADHESIVE		STEATITE
	2CR-125	ADHESIVE		STEATITE
3M	SJ8069X	ADHESIVE		CORDIERITE
	SJ8072	ADHESIVE		STEATITE
CHEMETRON	69-300000-2	ADHESIVE		CORDIERITE
	69-300000-4	ADHESIVE		CORDIERITE
VARIOS	VLG/02	MAGNETS		CORDIERITE

CERAMIC BACKING DATA SUMMARY
TABLE 3.1

IV. EVALUATION PLAN AND PROCEDURE

Representative ceramic backing systems from Chemetron, Kuder, 3-M and Varios, as previously identified in Table 3.1, were evaluated in four "Phases". Each Phase, detailed in Charts I, II, III & IV, corre-spends to the following FCAW or SAW variations comnonly encountered in a production environment.

- o Phase I — All Position, .052" and 1/16" Diameter, E70T-1 Flux-cored Wire with C-25 Shielding
- o Phase II — Flat Position, 5/64 and 3/32" Diameter, E70T-1 Flux-cored Wire with CO_2 Shielding
- o Phase III — All Position, 5/64" and Flat Position 3/32" E70T-G Self-Shielded Flux-cored Wire
- o Phase IV — Flat Position Single and Tandem Submerged Arc Wire

The evaluation plan made extensive use of the following definitions:

PHASE: One of the four general FCAW or SAW processes or variations evaluated. The four phases correspond to Charts I, II, III and IV.

GROUP: Within a phase, a specific combination of welding variables as identified in Charts I, II, III or IV and assigned a unique letter identification by these Charts.

TEST ASSEMBLY: TWO base metal plates partially or completely welded in accordance with one of the group/backing combinations identified in Charts I, II, III or IV and Table 4.1.

TEST COUPON: The one assembly from each group/backing combination which, having passed visual and radiographic examination, was selected for mechanical and chemical evaluation in accordance with Charts I, II, 111 or IV.

TEST SPECIMEN: One of the mechanical or chemical test pieces removed from a coupon and identified by Figure 4.1.

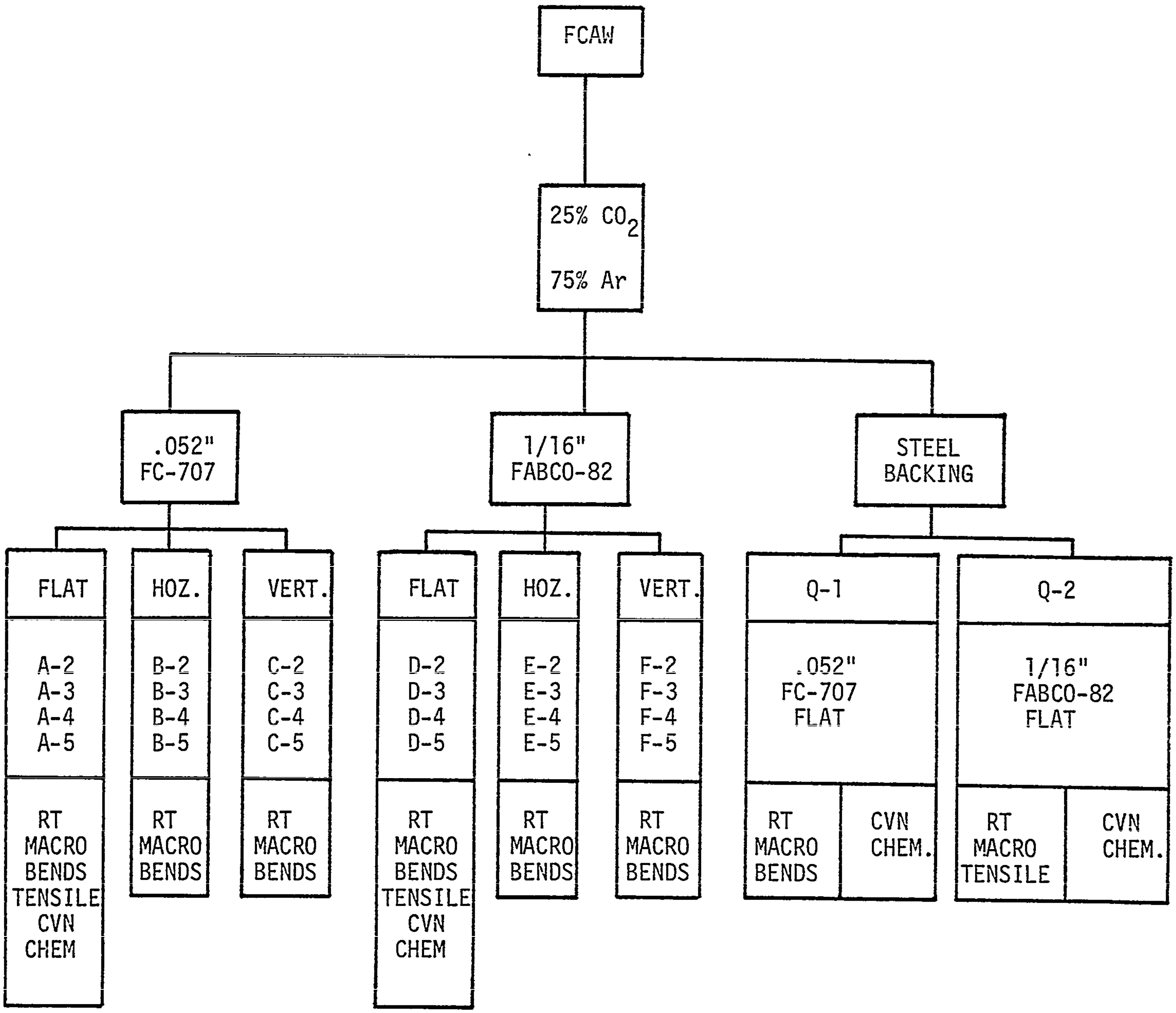
Charts I through IV identify, for each of the four (4) test phases, the specific groups, assigns each group an alpha identifier and specifies the testing/evaluation performed on each coupon in the group. Table 4.1 identifies the type of backing evaluated with each group. Test assemblies made within a given group with a given backing are numbered sequentially.

EXAMPLE:

	From Chart I, we know this assembly was made with FCAW, C-25 shielding, .052″ diameter wire in the flat position.
A-2-1	From Table 4.1, we know this assembly was made with Kuder Type lCR-062 ceramic backing.
	This was the first assembly made with these specific parameters and backing type. Subsequent assemblies will exist only if this one fails visual or radiographic examination.

After welding a sufficient number of “practice” plates for approximate identification of current, voltage, technique, etc., test assemblies were prepared for each combination of variables identified in Charts I through IV. All test assemblies were made by butt welding two 1/2″ thick A36 plates. The plates/welds varied in length from approximately 12″ to 18″ assuring sufficient material for removal of appropriate test specimens should the assembly be selected for evaluation. Test assemblies with, visually acceptable beads were radiographed. If no internal defects were identified by radiography, the welding parameters were verified by welding and visually and radiographically examining a second coupon using the same parameters as the original.

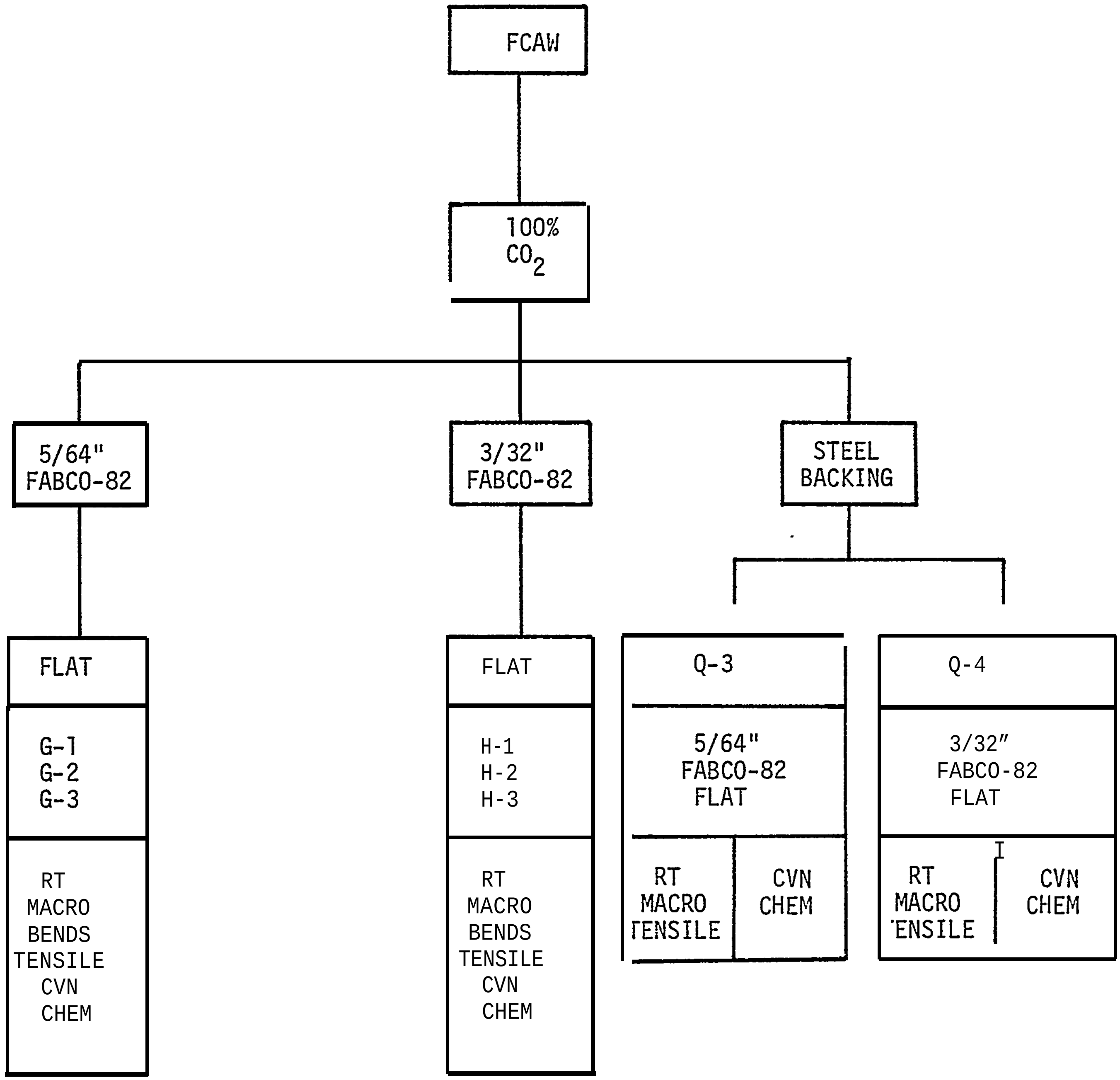
Upon successful verification, the specimens for tests identified in Charts I through IV were removed from the coupon for evaluation. Figure 4.1 identifies the orientation (though not necessarily the removal sequence) of the various test specimens. The tensile and bend specimens were machined and tested in accordance with ASME Section IX. The Charpy Vee Notch specimens (five to a set) were machined and tested at +20°F in accordance with the appropriate parts of ASTM A370. The specimen identified "CHEM" was machined so the bottom surface would lie in the approximate mid-thickness of the root bead and the top surface would lie in the approximate mid-thickness of the second bead permitting spectrographic analysis of the root and second bead. Macrophotographs were obtained either from the "CHEM" specimen before reduction in thickness or from excess coupon material.



FC-707 is manufactured by Linde and complies with A5.20, E70T-1

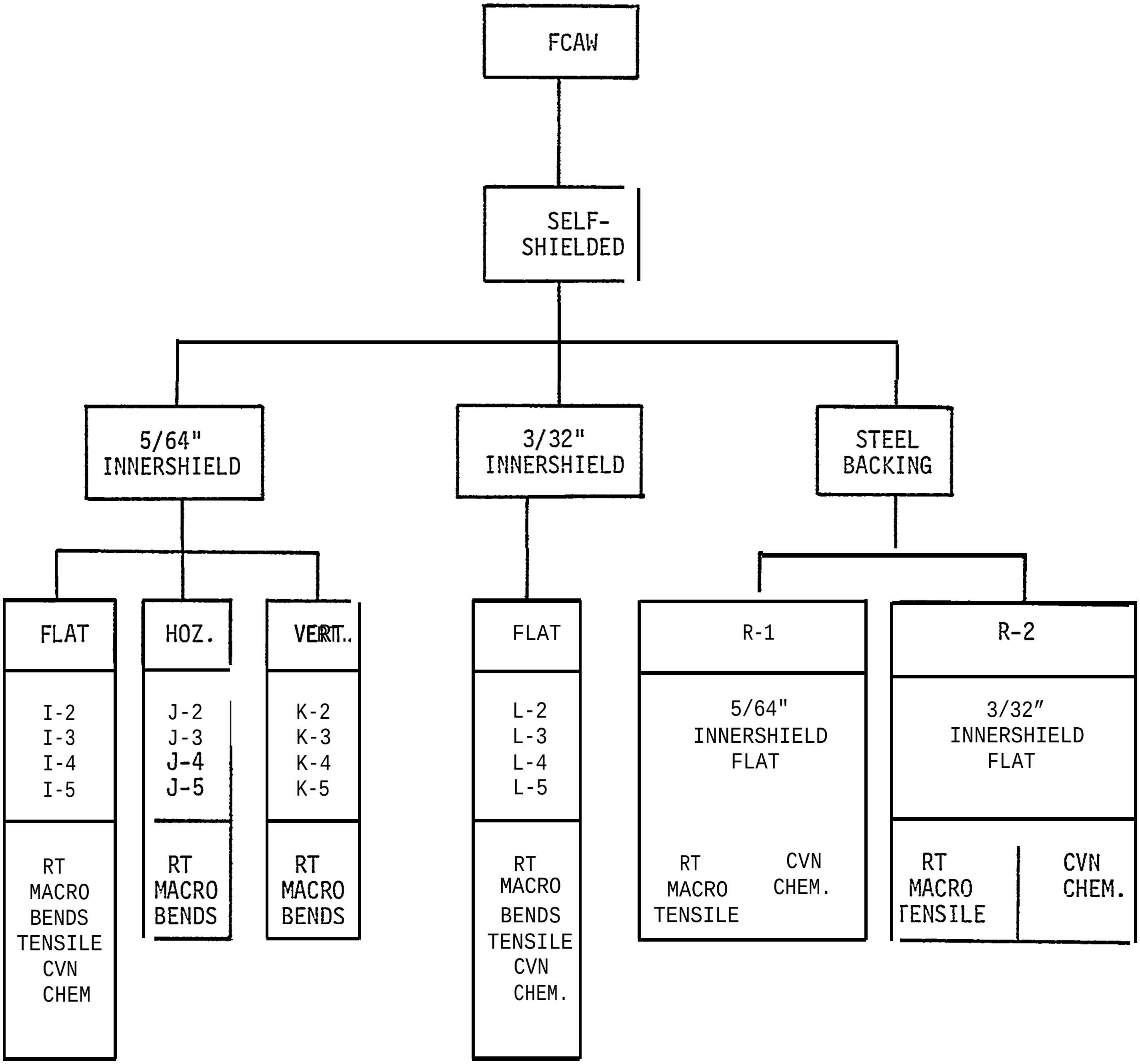
FABCO-82 is manufactured by Hobart and complies with A5.20, E70T-1

CHART I
PHASE I EVALUATION PLAN



FABCO-82 is manufactured by Hobart and complies with A5.20, E70T-1

CHART II
PHASE II EVALUATION PLAN



INNERSHIELD is manufactured by Lincoln and complies with A5.20, E70T-G.
The type used was NR203-M.

CHART III
PHASE III EVALUATION PLAN

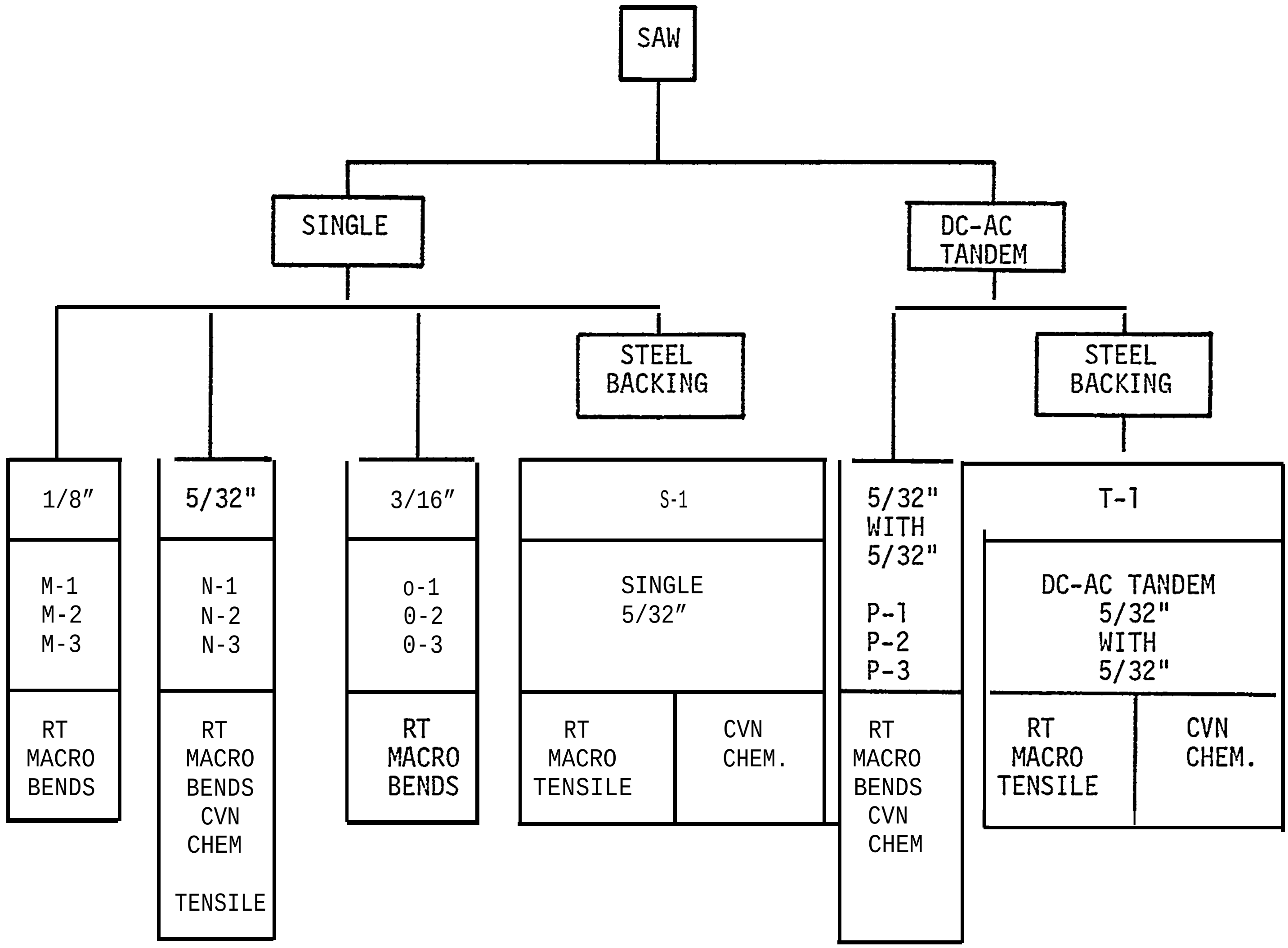


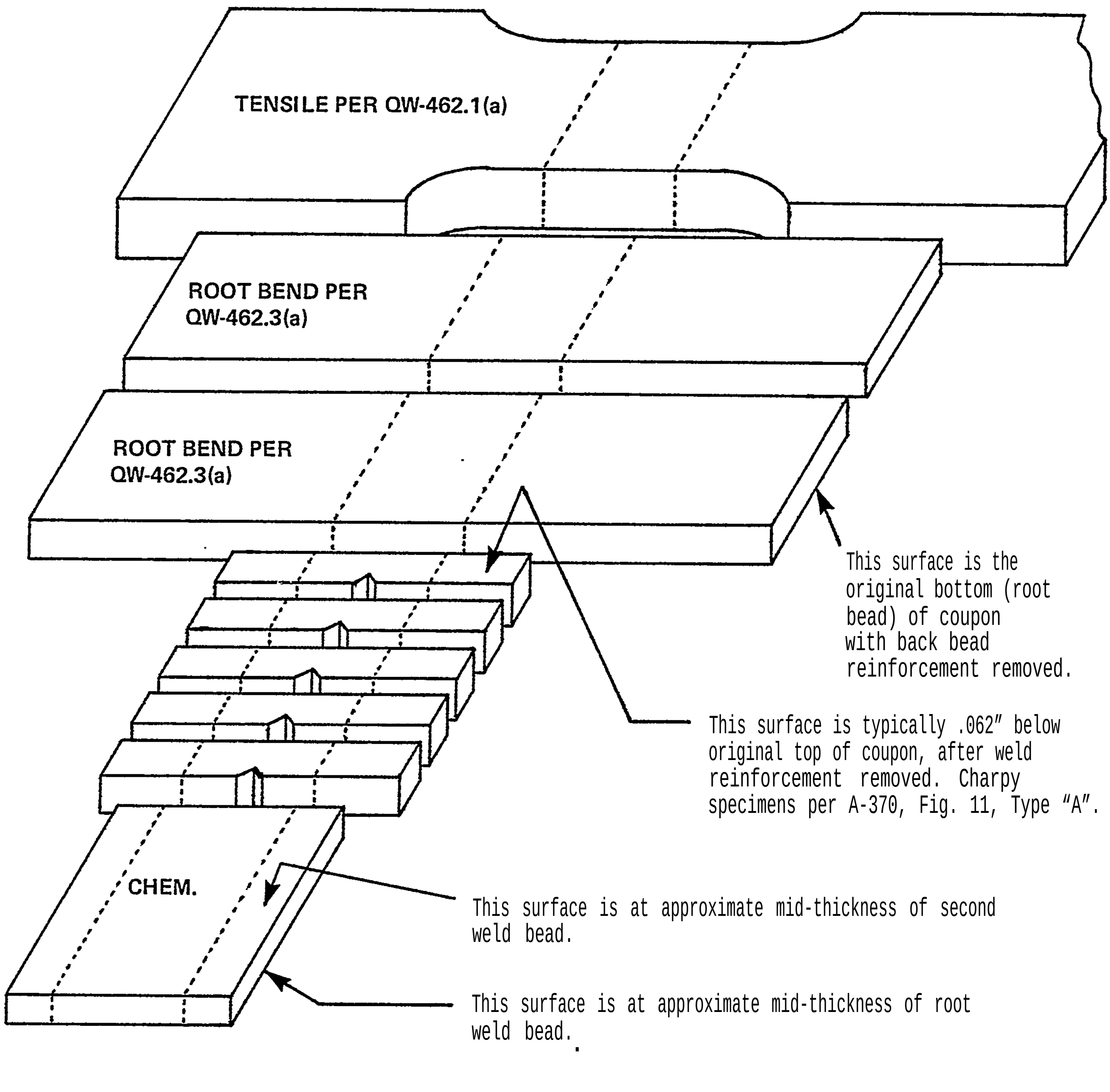
CHART IV
PHASE IV EVALUATION PLAN

A-2	KUDER	1CR-062
A-3		SJ8069X
A-4	CHEMETRON	69-300000-2
A-5	VARIOS	VLG-02
B-2	KUDER	1CR-062
B-3	3M	SJ8069X
B-4	CHEMETRON	69-300000-2
B-5	VARIOS	VLG-02
c-2	KUDER	lCR-062
c-3	3M	SJ8069X
c-4	CHEMETRON	69-300000-2
c-5	VARIOS	VLG-02
D-2	KUDER	1CR-062
D-3	3M	SJ8069X
D-4	CHEMETRON	69-300000-2
D-5	VARIOS	VLG-02
E-2	KUDER	1 R-062
E-3	3M	SJ8069X
E-4	CHEMETRON	69-300000-2
E-5	VARIOS	VLG-02
F-2	KUDER	lCR-062
F-3	3M	SJ8069X
F-4	CHEMETRON	69-300000-2
F-5	VARIOS	VLG-02
G-1	KUDER	2CR-125
G-2	3M	SJ8072X
G-3	CHEMETRON	69-300000-4
H-1	KUDER	2CR-125
H-2	3M	SJ8072X
H-3	CHEMETRON	69-300000-4
I-2	KUDER	1 CR-062
I-3	3!4	SJ8069X
I-4	CHEMETRON	69-300000-2
I-5	VARIOS	VLG-02

J-2	KUDER	1 CR-062
J-3	3M	SJ8069X
J-4	CHEMETRON	69-300000-2
J-5	VARIOS	VLG-02
K-2	KUDER	lCR-062
K-3	3M	SJ8069X
K-4	CHEMETRON	69-300000-2
K-5	VARIOS	VLG-02
L-2	KUDER	1 CR-062
L-3	3M	SJ8069X
L-4	CHEMETRON	69-300000-2
L-5	VARIOS	VLG-02
M-1	KUDER	2CR-125
M-2	3M	SJ8072X
M-3	CHEMETRON	69-300000-4
N-1	KUDER	2CR-125
N-2	3M	SJ8072X
N-3	CHEMETRON	69-300000-4
0-l	KUDER	2CR-125
o-2	3M	SJ8072X
o-3	CHEMETRON	69-300000-4
P-1	KUDER	2CR-125
P-2	3M	SJ8072X
P-3	CHEMETRON	69-300000-2
Q-1	A36 STEEL	(.052″ WIRE)
Q-2	A36 STEEL	(1/16″ WIRE)
Q-3	A36 STEEL	(5/64″ WIRE)
Q-4	A36 STEEL	(3/32″ WIRE)
R-1	A36 STEEL	(5/64" WIRE)
R-2	A36 STEEL	(3/32" WIRE)
S-1	A36 STEEL	
T-1	A36 STEEL	

TABLE 4.1
IDENTIFICATION OF CERAMIC TYPE TO TEST COUPONS

All Specimens centered on weld centerline.



TEST SPECIMEN ORIENTATION
FIGURE 4.1

V. TEST RESULTS

Table 5.1 identifies the welding data and NDE and mechanical testing results applicable for the coupons evaluated. Similar detailed data for all test assemblies is presented in Appendix A. Details of joint designs identified in Table 5.1 are given in Table 5.2. Table 5.3 additionally defines the torch angles presented in Table 5.1.

The Phase I, II, III and IV spectrographic chmical analysis results are given in Tables 5.4.1, 5.4.2, 5.4.3 and 5.4.4, respectively. Additionally, energy dispersive X-ray (EDX) analysis of each unfused ceramic type is displayed in Table 5.5.

The information accumulated in the program and exhibited in Tables 5.1 through 5.5 and in Appendix A permitted evaluation of ceramic backing with regard to:

1) weld soundness
2) toughness
3) bead shape
4) stops and starts
5) ceramic attaching methods
6) ceramic neutrality

A discussion of each area follows in the analysis portion of the report.

FCAW W/C-25 OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

Test No.	Joint No.	Ceramic	Wire Type	Manufacturer	Identification	Diameter	75AR-25CO_2	CO_2	C.F.H. Gas Flow	Gasless	D.C.S.P.	D.C.R.P.	Plate Thickness	Pass No.	Amperage	Voltage	Travel Speed	Torch Angle	Progression	String	Weave	Radiograph	Root Bends & Tensile 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	$\bar{X}$
A-2	7	A	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		38	39	50	45	48	41
FLAT POSITION														2-4	260	28	13.5	60°	FH	X		U= 67,567					33	32	44	37	41	37
																						Y=					10	10	20	20	20	16
A-3	6	C	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		30	39	42	43	54	42
FLAT POSITION														2-4	260	28	12-13.5	60°	FH	X		U= 66,622					23	30	33	39	41	33
																						Y=					10	10	15	20	30	17
A-4	6	F	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		30	40	38	37	46	38
FLAT POSITION														2-4	260	28	12-13.5	60°	FH	X		U= 67,617					25	21	26	26	34	28
																						Y=					10	10	10	15	20	13
A-5	7	E	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		23	34	29	30	26	28
FLAT POSITION														2-4	260	28	12-13.5	60°	FH	X		U= 65,559					18	35	24	26	30	26
																						Y=					5	10	5	5	15	8
B-2	10	A	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	280	25	7.5	50°-60°	BH	X		X	X		X		--	--	--	--	--	--
HORIZONTAL POSITION														2-5	280	25	13.5-14.5	50°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
B-3	4	C	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	280	25	7.5	50°-60°	BH	X		X	X		X		--	--	--	--	--	--
HORIZONTAL POSITION														2-4	280	25	13.5-14	15°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
B-4	4	F	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	250	25	7 - 8	50°-60°	BH	X		X	X		X		--	--	--	--	--	--
HORIZONTAL POSITION														2-4	250	25	13-14	15°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
B-5	4	E	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	260	26	7.5 - 8	50°-60°	BH	X		X	X			X	--	--	--	--	--	--
HORIZONTAL POSITION (SEE NOTE B-5)														2-6	260	26	13 - 14	20°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
C-2	12	A	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	220	24	4 - 5	10°-15°	BH		X	X	X		X		--	--	--	--	--	--
VERTICAL POSITION (SEE NOTE C-2)														2-3	220	24	4 - 5.5	15°-20°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
C-3	13	C	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	240	24	4	15°-20°	BH		X	X	X		X		--	--	--	--	--	--
VERTICAL POSITION (SEE NOTE C-2)														2-3	240	24	7 - 9	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
C-4	8	F	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	240	24	4	15°-20°	BH		X	X	X		X		--	--	--	--	--	--
VERTICAL POSITION (SEE NOTE C-2)															240	24	7 - 9	15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
C-5	10	E	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	240	24	4.5	15°-20°	BH		X	X	X		X		--	--	--	--	--	--
VERTICAL POSITION (SEE NOTE C-2)															240	24	8 - 9	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
Q-1	3	--	E70T-1	Linde	FC-707	.052	X		40			X	.500	1	240	28	12	15°	BH	X		X	X		X		30	18	20	22	22	22
FLAT POSITION (SEE NOTE Q-1)														2-7	240	28	7 - 12	15°	BH		X	U= 71,932					24	15	17	18	18	18
																						Y= 48,660					20	25	25	30	30	26

CERAMIC GEOMETRY

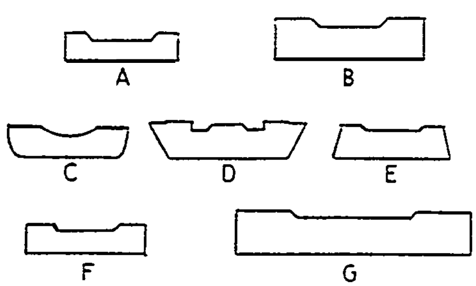


TABLE 5.1
Summary of Welding Data and NDE and Mechanical Testing Results for Test Coupons (pg. 1 of 6)

PHASE l

NOTES

B-5 Radiography of cupon B-5 identified minor Chevron. A root band specimen takan from this area failad, allowing visual impection of the affected area

C-2 Welded in the vartical up position. The torch was bald at a 15 angle from the vartical plana. Progression was backhand, which was necessary to maintain arc.

O-1 Weldad over A-36 backing for chemistry comparison in ceramic nautrality evaluation.

FCAW W/C-25 OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

Test No.	Joint No.	Ceramic	Wire Type	Manufacturer	Identification	Diameter	75Ar-25CO₂	CO₂	C.F.H. Gas Flow	Gasless	D.C.S.P.	D.C.R.P.	Plate Thickness	Pass No.	Amperage	Voltage	Travel Speed	Torch Angle	Progression	String	Weave	Radiograph	Root Bends & Tensile 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	X̄
D-2	10	A	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	30	8	50°-60°	BH	X		X	X	--	X	--	21	21	20	20	21	20
FLAT POSITION														2-4	260	30	6-7	15°	BH	X		U= 67,705					17	14	13	16	14	14
																						Y=					10	10	10	10	10	10
D-3	5	C	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	30	7.5 - 8	50°-60°	BH	X		X	X	--	X	--	39	32	32	33	32	33
FLAT POSITION														2-4	260	30	6-8	15°	BH		X	U= 65,407					32	27	23	24	22	25
																						Y=					15	10	10	10	10	11
D-4	9	F	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	30	7.5 - 8	50°-60°	BH	X		X	X	--	X	--	21	28	30	30	27	27
FLAT POSITION														2-4	260	30	6 - 7.5	15°	BH		X	U= 64,859					16	28	27	29	20	24
																						Y=					5	10	15	15	10	11
D-5	11	E	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	30	7 - 8	50°-60°	BH	X		X	X	--	X	--	20	23	19	11	28	20
FLAT POSITION														2-4	260	30	6 - 8	15°	BH		X	U= 53,405					20	20	20	13	25	19
																						Y=					10	10	5	5	10	8
E-2	33	A	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	25	7 - 7.5	50°-60°	B^d	X		X	X	--	X	--	--	--	--	--	--	--
HORIZONTAL POSITION														2-5	260	25	13-14	15°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
E-3	34	C	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	25	7-7.5	50°-60°	BH	X		X	X	--	X	--	--	--	--	--	--	--
HORIZONTAL POSITION														2-5	260	25	13 - 14	15°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
E-4	34	F	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	25	7 - 7.5	50°-60°	BH		X	X	X	--	X	--	--	--	--	--	--	--
HORIZONTAL POSITION														2-5	260	25	13 - 14.5	15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
E-5	35	E	E70T-1	Hobart	Fabco 82	1/16"	X		40			X	.500	1	260	25	7-7.25	50°-60°	BH	X		X	X	--	X	--	--	--	--	--	--	--
														2-5	260	25	13 - 14	15°	FH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
F-2	2	A	E70T-1	Linde	FC-707	1/16"	X		45			X	.500	1	220	22	4 - 4.5	15°	BH		X	X	X	--	X	--	--	--	--	--	--	--
VERTICAL POSITION (SEE NOTE F-2)														2-4	230	22	5 - 9	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
F-3	2	C	E70T-1	Linde	FC-707	1/16"	X		45			X	.500	1	220	22	5.5 - 6	10°-15°	BH		X	X	X	--	X	--	--	--	--	--	--	--
VERTICAL POSITION														2-3	230	22	6 - 8.5	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
F-4	14	F	E70T-1	Linde	FC-707	1/16"	X		45			X	.500	1	230	22	5.25 - 6	10°-15°	BH		X	X	X	--	X	--	--	--	--	--	--	--
VERTICAL POSITION														2-3	230	22	6 - 7.5	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
F-5	1	E	E70T-1	Linde	FC-707	1/16"	X		45			X	.500	1	230	22	5.5 - 6	10°-15°	BH		X	X	X	--	X	--	--	--	--	--	--	--
VERTICAL POSITION														2-3	230	22	7 - 7.5	10°-15°	FH		X						--	--	--	--	--	--
																											--	--	--	--	--	--
Q-2	3	--	E70T-1	Linde	FC-707	1/16"	X		45			X	.500	1	280	27	10 - 11	15°	FH	X		X	X	--	X	--	21	21	20	20	21	21
FLAT POSITION (SEE NOTE Q-2)														2	280	27	7 - 8	15°	FH		X	U= 67,705					17	14	13	16	14	15
														3-6	300	28	12.5-15	15°	FH	·	X	Y= ------					10	10	10	10	10	10

CERAMIC GEOMETRY

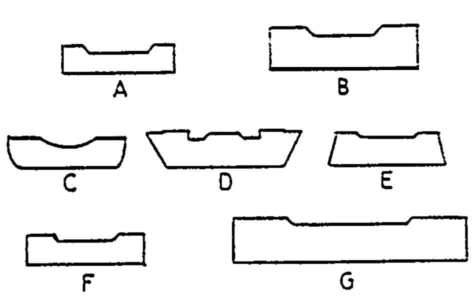


TABLE 5.1 (Cont.)

Summary of Welding Data and NDE and Mechanical Testing Results for Test Coupons (pg. 2 of 6)

PHASE I (CONTINUED)

NOTES:

F-2 A 15 work angle in conjunction with the 50 -60 lead angle was necessary to aid in filling the "key hole" effect.

Q-2 Welded over A-36 backing for chemistry comparison in caramic neutrality evaluation.

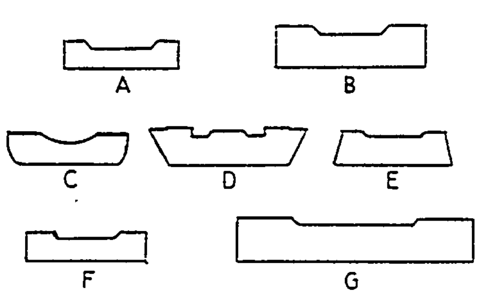
FCAW W/CO_2 OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75AR-25CO_2	CO_2	C.F.H. GAS FLOW	GASLESS	D.C.S.P.	D.C.R.P.	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	X̄
G-1	6	B	E70T-1	Hobart	Fabco 82	5/64"		X	40			X	.500	1	430	31	9.5 - 10	50°-60°	BH	X		X	X		X		17	17	16	13	13	15
FLAT POSITION														2-3	430	31		15°-20°	BH	X		U= 65,285					10	8	11	9	6	9
																						Y= 30,560					10	5	5	10	5	7
G-2	5	D	E70T-1	Hobart	Fabco 82	5/64"		X	40			X	.500	1	390	31	9 - 10.5	50°-60°	BH	X		X	X		X		80	12	10	12	10	25
FLAT POSITION														2-3	390	31	11 - 15	10°-15°	BH	X		U= 65,007					61	13	14	13	10	22
																						Y= 43,243					60	10	10	10	10	20
G-3	5	G	E70T-1	Hobart	Fabco 82	5/64"		X	40			X	.500	1	360	27	8.5 - 9	50°-60°	BH	X		X	X		X		16	13	10	9	10	11
FLAT POSITION														2-3	360	27	9 - 10	15°-20°	BH		X	U= 65,593					18	14	12	8	11	12
																						Y= 42,606					15	10	10	5	10	10
Q-3	3	--	E70T-1	Hobart	Fabco 82	5/64"		X	40			X	.500	1	320	28	11.5 - 12	15°	FH	X		X	X		X		18	27	25	21	25	24
FLAT POSITION (SEE NOTE Q-3)														2	320	28	10.5 - 12	15°	FH		X	U= 74,270					18	22	23	19	26	21
														3-6	320	28	15 - 16	15°	FH	X		Y= 48,957					25	30	20	20	25	24
H-1	15	B	E70T-1	Hobart	Fabco 82	3/32"		X	40			X	.500	1	400	28	8.5 - 9	50°-60°	BH	X		X	X		X		16	14	20	16	16	17
FLAT POSITION														2	400	28	11 - 12	15°	BH	X		U= 70,914					14	13	18	17	15	15
														3-4	400	28	11 - 15	15°	BH		X	Y= 45,429					10	10	15	10	15	12
H-2	16	D	E70T-1	Hobart	Fabco 82	3/32"		X	40			X	.500	1	400	28	8.5 - 9	50°-60°	BH	X		X	X		X		17	19	14	15	12	15
FLAT POSITION														2	400	28	11 - 12	15°	BH	X		U= 70,200					16	22	14	14	15	16
														3	400	28	7 - 8	15°	BH		X	Y= 44,269					10	10	10	10	10	10
H-3	15	G	E70T-1	Hobart	Fabco 82	3/32"		X	40			X	.500	1	400	28	9 - 10	50°-60°	BH	X		X	X		X		13	14	15	17	14	15
FLAT POSITION														2	400	28	11 - 12	15°	BH	X		U= 70,707					13	12	15	17	16	15
														3	400	28	7.25 - 9	15°	BH		X	Y= 47,330					10	10	10	10	10	10
Q-4	17	--	E70T-1	Hobart	Fabco 82	3/32"		X	40			X	.500	1	400	28	13	15°	BH	X		X	X		X		26	28	26	30	24	27
FLAT POSITION (SEE NOTE Q-4)														2-3	400	28	7.75 - 9	15°	BH		X	U= 72,546					25	28	25	26	32	27
																						Y= 50,071					25	30	20	20	25	24

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE and Mechanical Testing Results for Test Coupons (pg. 3 of 6)

PHASE II

CERAMIC GEOMETRY



NOTES:

Q-3 Welded over A-36 backing for chemistry comparison in the ceramic neutrality evaluation

Q-4 Welded over A-36 backing for chemistry comparison in the ceramic neutrality evaluation

FCAW SELF-SHIELDED OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

Test No.	Joint No.	Ceramic	Wire Type	Manufacturer	Identification	Diameter	75AR-25CO2	CO2	C.F.H. Gas Flow	Gasless	D.C.S.P.	D.C.R.P.	Plate Thickness	Pass No.	Amperage	Voltage	Travel Speed	Torch Angle	Progression	String	Weave	Radiograph	Root Bends & Tensile 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	X̄
I-2	18	A	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	340	20	7 - 8	25°-35°	BH	X		X	X		X		41	76	114	61	83	75
														2-4	340	20	7 - 8	20°	BH		X	U= 67,669					35	53	64	44	52	50
			FLAT POSITION																			Y= 30,880					20	25	45	20	30	28
I-3	19	C	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	340	20	7 - 8	35°-45°	BH	X		X	X		X		56	61	52	46	28	58
			FLAT POSITION											2-4	340	20	7 - 8	15°-20°	BH		X	U= 67,359					44	45	43	43	47	44
																						Y= 32,300					15	25	15	30	40	25
I-4	20	F	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	340	20	7.5 - 9	45°-50°	BH	X		X	X		X		60	23	44	31	54	42
			FLAT POSITION											2-5	340	20	8 - 10	15°-20°	BH		X	U= 67,514					43	25	32	26	36	33
																						Y= 31,680					10	5	15	5	15	10
I-5	19	E	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	340	20	7.5 - 9	45°-50°	BH	X		X	X		X		80	57	73	84	66	72
														2-4	340	20	8 - 10	15°-20°	BH		X	U= 66,622					60	50	62	58	46	55
			FLAT POSITION																			Y= 44,043					30	10	30	35	30	27
J-2	15	A	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	250	20	4.5 - 6	NOTE	BH	X		X	X		X		--	--	--	--	--	--
														2-6	250	20	13 - 16	J-2	BH	X							--	--	--	--	--	--
			HORIZONTAL POSITION																								--	--	--	--	--	--
J-3	4	C	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	220	20	4 - 5	NOTE	BH	X	.	X	X		X		--	--	--	--	--	--
														2-6	220	20	12.5 -15	J-2	BH	X							--	--	--	--	--	--
			HORIZONTAL POSITION																								--	--	--	--	--	--
J-4	15	F	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	250	20	5.25 - 6	NOTE	BH	X		X	X		X		--	--	--	--	--	--
			HORIZONTAL POSITION											2-6	250	20	13 - 15	J-2	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
J-5	15	E	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	250	20	5.5 - 6	NOTE	BH	X		X	X		X		--	--	--	--	--	--
														2-6	250	20	13 - 17	J-2	BH	X							--	--	--	--	--	--
			HORIZONTAL POSITION																								--	--	--	--	--	--
K-2	30	A	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	240	19	4- 4.5	NOTE	BH		X	X	X		X		--	--	--	--	--	--
														2-3	240	19	5 - 6	K-2	FH		X						--	--	--	--	--	--
			VERTICAL POSITION																								--	--	--	--	--	--
K-3	31	C	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	240	19	4.5 - 5	NOTE	BH		X	X	X		X		--	--	--	--	--	--
														2-3	240	19	5 - 6	K-2	FH		X						--	--	--	--	--	--
			VERTICAL POSITION																								--	--	--	--	--	--
K-4	31	F	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	240	19	4 - 4.5	NOTE	BH		X	X	X		X		--	--	--	--	--	--
														2-3	240	19	4.5 - 6	K-2	FH		X						--	--	--	--	--	--
			VERTICAL POSITION																								--	--	--	--	--	--
K-5	32	E	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	240	19	4 - 4.5	NOTE	BH		X	X			X		--	--	--	--	--	--
														2-3	240	19	5 - 6	K-2	FH		X						--	--	--	--	--	--
			VERTICAL POSITION																								--	--	--	--	--	--
R-1	3	--	E70T-G	Lincoln	NR-203-M	5/64"				X	X		.500	1	250	20	10	15°	BH	X		X	X		X		66	73	73	92	78	76
														2-3	250	20	11 - 12	15°	BH	X		U= 72,263					55	45	60	66	64	58
			FLAT POSITION (SEE NOTE R-1)																			Y= 46,715					60	45	65	75	70	63

CERAMIC GEOMETRY

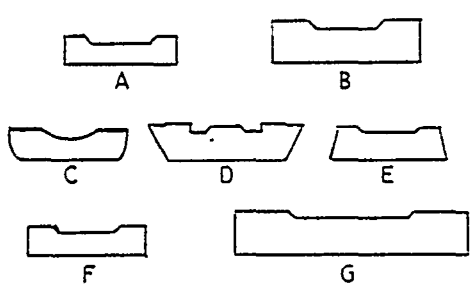


TABLE 5.1 (Cont)
Summary of Welding Data and NDE and Mechanical Testing Results for Test Coupons (pg. 4 of 6)

PHASE III

NOTES:

R-1 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation

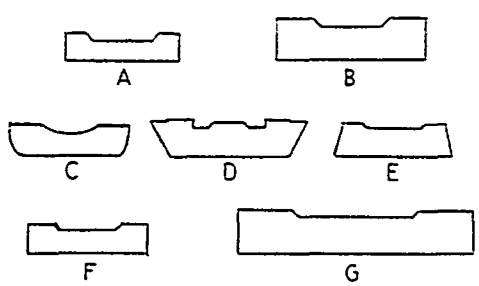
FCAW SELF-SHIELDED OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

Test No.	Joint No.	Ceramic	Wire Type	Manufacturer	Identification	Diameter	75AR-25CO₂	CO₂	C.F.H. Gas Flow	Gasless	D.C.S.P.	D.C.R.P.	Plate Thickness	Pass No.	Amperage	Voltage	Travel Speed	Torch Angle	Progression	String	Weave	Radiograph	Root Bends & Tensile 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	$\bar{X}$
L-2	13	A	E70T-G	Lincoln	NR-302	3/32"				X		X	.500	1	400	28	11 - 12	45°-55°	BH	X		X	X		X		65	55	70	80	66	66
FLAT POSITION														2-4	400	28	12 - 13	15°	BH	X		U= 71,866					52	52	59	64	56	57
																						Y= 48,746					60	45	50	65	55	55
L-3	13	C	E70T-G	Lincoln	NR-302	3/32"				X		X	.500	1	400	28	13.5 - 14	45°-55°	BH	X		X	X		X		69	49	68	71	62	6[illegible]
FLAT POSITION														2	400	28	11 - 12	15°	BH	X		U= 71,332					62	47	61	58	55	57
														3	400	28	7.5 - 8	15°	BH		X	Y= 45,652					50	30	65	65	55	53
L-4	16	F	E70T-G	Lincoln	NR-302	3/32"	·			X		X	.500	1	400	25	13 - 14	45°-55°	BH	X		X	X		X		57	70	60	39	44	54
FLAT POSITION														2	400	25	9 - 10	15°	BH	X		U= 70,518					49	55	49	37	38	45
														3	400	25	8 - 9	15°	BH		X	Y= 45.684					40	65	50	25	35	43
L-5	16	E	E70T-G	Lincoln	NR-302	3/32"				X		X	.500	1	400	28	13 - 14	45°-55°	BH	X		X	X		X		69	84	66	87	68	75
FLAT POSITION														2	400	28	9 - 10	15°	BH	X		U= 58,060					62	72	57	72	63	65
														3	400	28	7 - 9	15°	BH		X	Y= 48,770					60	70	50	75	50	61
R-2	21	-	E70T-G	Lincoln	NR-302	3/32"				X		X	.500	1	400	28	9 - 10	15°	BH	X		X	X		X		38	64	59	70	66	59
FLAT POSITION														2-4	400	28	8 - 10	15°	BH		X	U= 72,650					40	56	50	57	55	52
																						Y= 50,997					40	50	40	50	60	48

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE and Mechanical Testing Results for Test Coupons (pg. 5 of 6)

PHASE III (CONTINUED)

CERAMIC GEOMETRY



NOTES:

R-2 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation

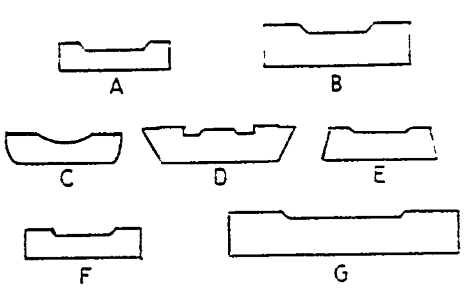
SAW OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

Test No.	Joint No.	Ceramic	Wire Type	Manufacturer	Identification	Diameter	75AR-25CO₂	CO₂	C.F.H. Gas Flow	Gasless	D.C.S.P.	D.C.R.P.	Plate Thickness	Pass No.	Amperage	Voltage	Travel Speed	Torch Angle	Progression	String	Weave	Radiograph	Root Bends & Tensile 1 P	1 F	2 P	2 F	CVN +20°F 1	2	3	4	5	X̄
M-1	22	B	EM12K	Linde	81	1/8"						X	.500	1	640	34	10	85°	BH	X		X	X		X		--	--	--	--	--	--
FLAT POSITION														2	500	38	10	85°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
M-2	23	D	EM12K	Linde	81	1/8"						X	.500	1	640	34	10	85°	BH	X		X	X		X		--	--	--	--	--	--
FLAT POSITION														2	500	36	10	85°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
M-3	22	F	EM12K	Linde	81	1/8"						X	.500	1	650	34	15	85°	BH	X		X	X		X		--	--	--	--	--	--
FLAT POSITION														2	450	35	10	85°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
N-1	23	B	EM12K	Linde	81	5/32"						X	.500	1	750	34	9.5	85°	BH	X		X	X		X		20	22	26	25	21	23
FLAT POSITION																						U= 68,619					21	23	28	29	25	25
																						Y= 45,077					5	5	5	5	5	5
N-2	23	D	EM12K	Linde	81	5/32"						X	.500	1	750	34	9.5	85°	BH	X		X	X		X		20	25	20	24	29	23
FLAT POSITION																						U= 68,516					21	26	21	25	30	25
																						Y= 45,076					5	5	5	5	5	5
N-3	23	F	EM12K	Linde	81	5/32"						X	.500	1	750	34	9.5	85°	BH	X		X	X		X		11	15	18	22	19	17
FLAT POSITION														2	640	38	10	85°	BH	X		U= 68,486					15	22	20	24	25	21
																						Y= 46,494					10	15	10	15	10	12
O-1	27	B	EM12K	Linde	81	3/16"						X	.500	1	820	34	11	85°	BH	X		X	X		X		--	--	--	--	--	--
FLAT POSITION														2	800	40	15	85°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
O-2	28	D	EM12K	Linde	81	3/16"						X	.500	1	820	33	11	85°	BH	X		X	X		X		--	--	--	--	--	--
FLAT POSITION														2	820	33	15	85°	BH	X							--	--	--	--	--	--
																											--	--	--	--	--	--
O-3	29	G	EM12K	Linde	81	3/16"						X	.500	1	850	34	10.5	85°	BH	X		X	X		X		19	14	19	21	19	18
FLAT POSITION														2	750	40	15	85°	BH	X		U= 66,950					13	18	22	25	23	21
																						Y= 43,120					5	5	5	5	[illegible]	5
S-1	24	--	EM12K	Linde	81	3/16"						X	.500	1	750	38	10.5	85°	BH	X		X	X		X		19	14	19	21	[illegible]	18
FLAT POSITION (SEE NOTE S-1)														2-3	750	38	10.5	85°	BH	X		U= 66,950					13	18	22	25	23	21
																						Y= 43,120					5	5	5	5	5	5
P-3	25	F	EM12K	Linde	81	5/32"						X	.500	1-L	750	32	14	85°	BH	X		X	X		X		14	21	17	21	17	18
FLAT POSITION (SEE NOTE P-3)														1-T	600	40		15°	FH			U= 68,741					26	28	16	24	20	22
																						Y= 45,643					5	5	5	5	7	5
T-1	26	--	EM12	Linde	81	5/32"						X	.500	1-L	740	33	25	90°		X		X	X		X							
FLAT POSITION (SEE NOTE T-1)														1-T	620	40		15°	Fd			U= 68,393										
																						Y= 45,032										

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 6 of 6)

PHASE IV

CERAMIC GEOMETRY



NOTES:

S-1 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation

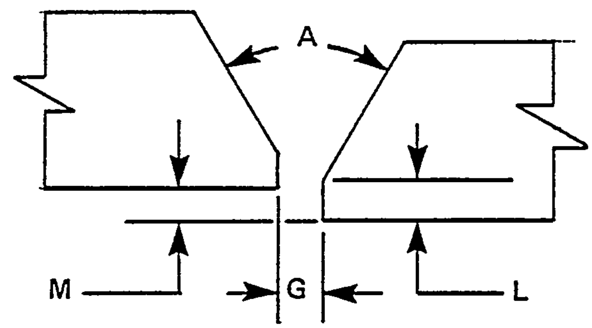
P-3 Welded with Tandom sub arc - designated in the pass column as 1-L (D.C. lead) and 1-T (A.C. trail).

T-1 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation

JOINT DESIGN DETAILS—ALL PHASES
TABLE 5.2

NO.	G	A	L	M
1	1/16" to 3/32"	60	—0—	—0—
2	3/32"	60	—0—	—0—
3	5/16"	60	—0—	—0—
4	1/8"	45	—0—	—0—
5	3/16"	45	—0—	—0—
6	7/32"	45	—0—	—0—
7	1/4"	45	—0—	—0—
8	1/8"	45	—0—	3/64"
9	3/16"	45	—0—	3/64"
10	5/32"	45	—0—	1/32"
11	3/16"	45	—0—	1/32"
12	1/8"	60	—0—	1/32"
13	5/32"	60	—0—	1/32"
14	1/16" to 3/32"	60	—0—	1/32"
15	1/8"	60	—0—	—0—
16	5/32"	60	—0—	—0—
17	11/32"	60	—0—	—0—
18	1/4"	60	—0—	1/32"
19	3/16"	60	—0—	—0—
20	3/16"	60	—0—	1/32"
21	3/8"	60	—0—	—0—
22	—0—	45	—0—	—0—
23	—0—	45	3/32"	—0—
24	1/4"	45	3/32"	—0—
25	0 to 1/16"	45	3/32"	—0—
26	3/8"	45	3/32"	—0—
27	0 to 1/32"	45	3/32"	1/64"
28	0 to 1/16"	45	—0—	1/32"
29	0 to 1/16"	45	—0—	—0—
30	1/16" to 1/8"	60	1/16" to 3/32"	—0—
31	3/32"	60	3/32"	—0—
32	3/32"	60	3/32" to 1/8"	1/32"

CONFIGURATION



CODE:

NO. = Joint Number
G = Gap
A = Angle
L = Land
M = Mismatch

NO.	G	A	L	M
33	5/32"	30	—0—	1/32"
34	5/32"	30	—0—	1/16"
35	5/32"	30	—0—	—0—

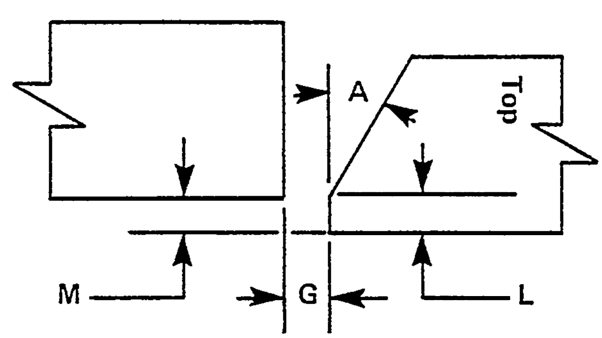
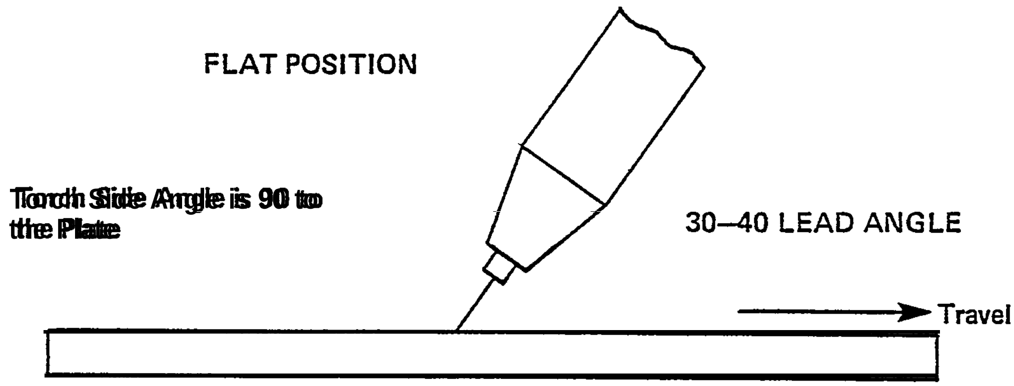
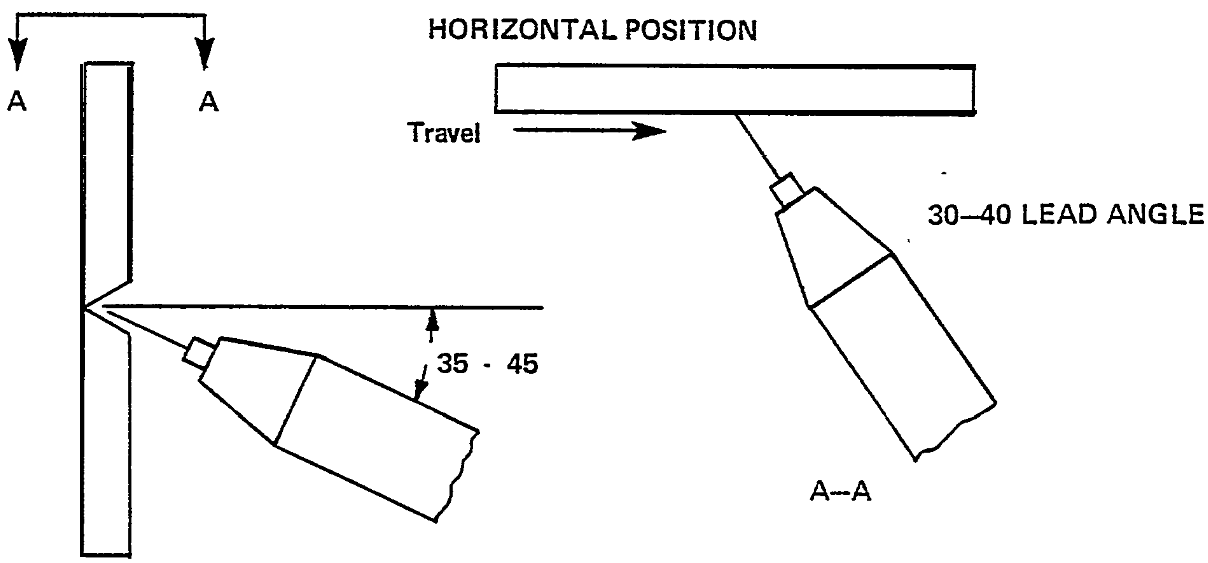


TABLE 5.3

OPTIMUM FCAW TORCH ANGLES FOR WELDING OVER CERAMIC BACKING





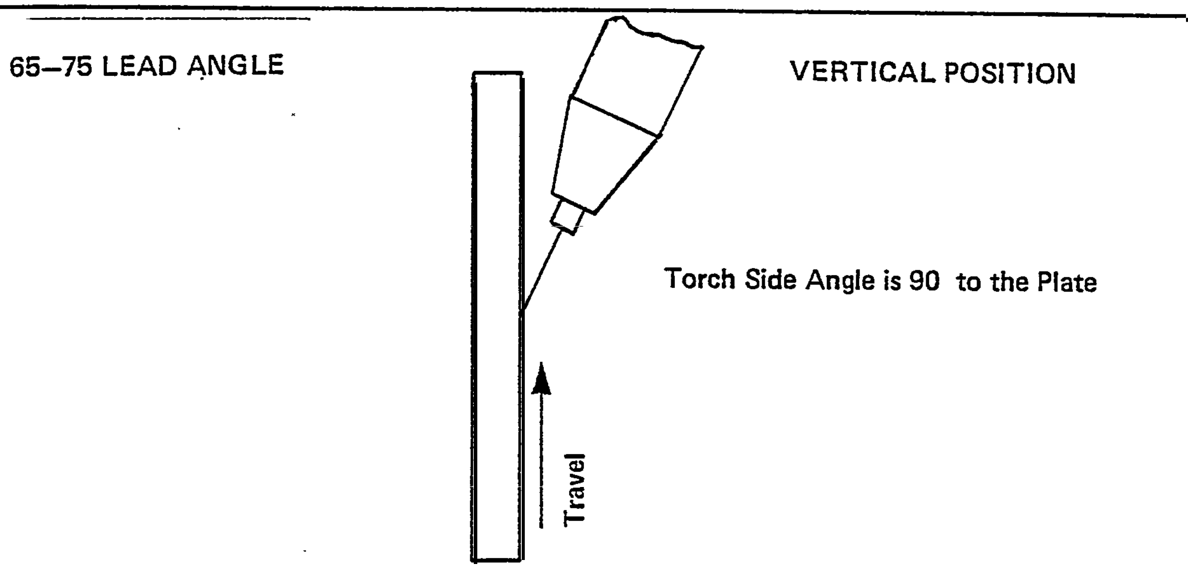


Table 5.4.1

Phase I Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti	Cr	Mo	V	CE
A-2	Root	98.179	.121	.027	.009	.832	.006	.644	.053	.033	.039	.036	.008	.013	.297
	Second	97.837	.104	.025	.011	1.201	.017	.592	.054	.016	.068	.045	.012	.018	.343
A-3	Root	98.219	.114	.025	.008	.954	.010	.469	.053	.015	.068	.041	.008	.016	.304
	Second	97.864	.102	.024	.009	1.222	.012	.557	.052	.017	.066	.046	.011	.018	.343
A-4	Root	98.229	.122	.030	.008	.824	.011	.591	.055	.034	.044	.033	.006	.013	.294
	Second	97.933	.110	.024	.007	1.212	.014	.498	.054	.015	.068	.041	.008	.016	.344
A-5	Root	98.262	.136	.026	.006	.888	.007	.489	.054	.030	.051	.032	.006	.013	.314
	Second	97.804	.106	.025	.007	1.265	.015	.564	.055	.020	.071	.042	.009	.017	.353
Q-1	Root	97.879	.084	.022	.018	1.301	.014	.495	.039	.004	.070	.042	.017	.015	.335
	Second	97.621	.069	.026	.016	1.455	.010	.597	.047	.003	.070	.050	.017	.019	.352
D-2	Root	98.309	.131	.025	.021	.872	.000	.484	.038	.054	.020	.022	.013	.011	.306
	Second	97.623	.121	.025	.023	1.517	.000	.527	.026	.028	.043	.028	.022	.017	.409
D-3	Root	98.515	.134	.024	.021	.743	.000	.399	.036	.049	.017	.040	.012	.010	.287
	Second	98.245	.128	.027	.023	1.087	.000	.348	.027	.030	.026	.028	.017	.014	.335
D-4	Root	98.611	.132	.018	.012	.749	.000	.340	.034	.049	.015	.019	.011	.010	.279
	Second	98.121	.126	.023	.018	1.167	.000	.406	.026	.027	.028	.025	.017	.016	.348
D-5	Root	98.609	.125	.017	.009	.698	.000	.417	.030	.043	.015	.018	.010	.009	.267
	Second	98.221	.122	.021	.016	1.091	.000	.389	.024	.024	.037	.024	.016	.015	.331
Q-2	Root	97.992	.125	.022	.025	1.291	.000	.434	.016	.008	.031	.023	.020	.013	.369
	Second	97.783	.112	.027	.029	1.426	.000	.490	.020	.011	.032	.029	.023	.018	.383
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	.228
HT. #633 - 02225HZ43		97.774	.051	.025	.009	1.373	.008	.549	.049	.006	.066	.053	.017	.020	.319
HT. #282B8		97.783	.114	.026	.028	1.435	.000	.479	.020	.016	.027	.030	.024	.088	.387

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Si}{24} + \frac{\%Cr}{5} + \frac{\%Mo}{4} + \frac{\%V}{14} + \frac{\%Ni}{40}$$

HT #282B8 was used for Q-2

HT #63302225H243 was used for all A series and Q-1 / HT #32128'1022 was used for all D series (none avail. for chem.)

Table 5.4.2

Phase 11 Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti.	Cr	Mo	V.	CE
G-1	Root	98.129	.117	.019	.007	.866	.000	.640	.03'8	.048	.025	.023	.013	.012	.298
	Second	98.102	.105	.017	.006	1.045	.000	.567	.033	.041	.029	.025	.016	.014	.314
G-2	Root	98.399	.124	.018	.004	.783	.000	.504	.047	.055	.018	.024	.014	.010	.286
	Second	98.509	.127	.021	.009	.798	.000	.358	.050	.073	.014	.022	.012	.007	.285
G-3	Root	98.087	.143	.018	l 003	1.046	.000	.464	.065	.064	.031	.041	.022	.011	.353
	Second	97.833	.110	.016	.010	1.243	.000	.587	.048	.046	.034	.036	.022	.015	.357
Q-3	Root	98.339	.138	.021	l 003	.899	.000	.273	.146	.070	.025	.058	.021	.007	.318
	Second	97.771	.089	.016	.008	1.313	.000	.596	.054	.030	.050	.034	.023	.016	.347
H-1	Root	97.709	.114	.016	.014	1,287	.000	.666	.048	.041	.039	.030	.020	.016	.369
	Second	97.537	.095	.015	.014	1,470	.000	.685	.042	.034	.039	.031	.020	.018	.382
H-2	Root	98.029	.132	.018	.011	.972	.000	.661	.049	.049	.025	.026	.015	.013	.333
	Second	97.514	.106	.017	.014	1.412	.000	.749	.043	.037	.043	.029	,019	.017	.385
H-3	Root	98.030	.120	.019	.013	.954	.000	.673	.051	.056	.028	.027	.015	.014	.319
	Second	97.712	.105	.012	.010	1.332	.000	.658	.038	.033	.036	.028	.019	.017	.367
Q-4	Root	97.806	.118	.012	.016	1.382	.001	.528	.027	.016	.041	.023	.017	.013	.381
	Second	97.588	.090	.014	,014	1 l 509	.000	.617	.031	.027	.042	.029	.021	.018	.380
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	.228
HT #l13122K8		98.215	.067	.010	.004	1.093	.000	.483	.018	.015	.027	.028	.022	.018	.282
HT 3 4302L8		98.020	.069	.008	.003	1.226	.000	.526	.031	.018	.029	.029	.021	.020	.308

HT. #/18122K8 was used for all G-series and Q-3. HT. #4302L8 was used for all H-Series and Q-4,

Table 5.4.3

Phase III Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti	Cr	Mo	V	CE
I-2	Root	97• 700	.119	.006	.005	1.294	.369	.368	.031	.045	.001	.024	.036	.002	.365
	Second	97.729	.106	.005	.005	1.428	.338	.258	.025	.036	.002	.025	.041	.002	.371
I-3	Root	97.728	.128	.006	.006	1.292	.371	.316	.033	.050	.003	.028	.037	.002	.372
	Second	97.768	.109	.007	.008	1.429	.311	.228	.028	.039	.002	.026	.043	.002	.374
I-4	Root	97.516	.126	.009	l 009	1.275	.358	.567	.032	.045	.003	.024	.033	.003	.376
	Second	97.632	.105	.007	.005	1.434	.364	.321	.026	.038	.002	.025	.039	.002	.373
I-5	Root	97.763	.121	.007	.006	1.241	l 354	.373	,032	.045	.002	.023	.031	.002	.357
	Second	97.755	.111	.005	.004	1.385	.360	.258	.024	.031	.002	.024	.039	.002	.368
R-1	Root	98.126	.132	.002	.014	1.154	.335	.183	.006	.001	.002	.014	.029	.002	.342
	Second	97.973	.103	.000	.006	1.286	.374	.182	.006	.006	.002	.019	.041	.002	.339
L-2	Root	98.343	.106	.005	.010	.797	.304	.331	.007	.020	.039	.012	.023	.003	.261
	Second	98.240	.112	.002	.004	.841	.375	.268	.008	.022	.082	.013	.030	.003	.274
L-3	Root	98.543	.121	.005	.008	.530	.324	.350	l 007	.016	.048	.021	.024	.003	.235
	Second	98.497	.108	.003	b 005	.575	.372	.277	.009	.022	.082	.015	.032	.003	.227
L-4	Root	98.270	.112	.004	.009	.850	.347	.275	.007	.020	.063	.013	.027	.003	.275
	Second	98.172	.100	.003	.006	.894	.373	.270	.008	.027	.096	.015	.033	.003	.272
L-5	Root	98.243	.107	.007	.014	.826	.312	.381	.007	.019	.044	.013	.024	.003	.270
	Second	98.207	.109	.003	l 005	.872	.375	.268	l 009	.021	.080	.014	.034	.003	.278
R-2	Root	98.327	.118	.002	.002	.826	' .370	.221	.006	.015	.071	.011	.028	.003	.275
	Second	98.292	.103	.003	.002	.829	.375	.233	.008	.020	.087	.013	.032	,003	.262
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	228
HT. #BB830		97.947	.100	.001	.009	1.320	.371	.172	.007	.007	.002	.020	.042	.002	.342
HT. #EKCF721		98.294	.084	.003	.000	.843	.369	.235	.009	.025	.091	.014	.030	l 003	.245

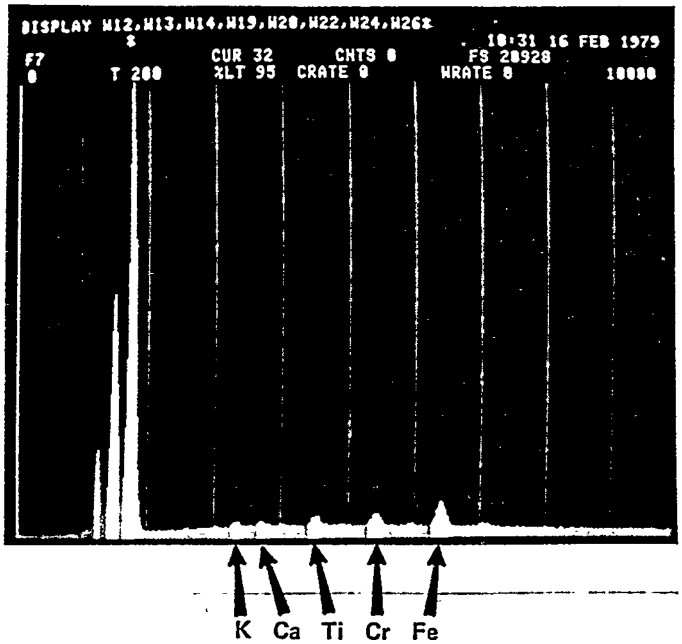
HT #BB830 (NR203M) was used for all I series and R-1   HT #EKCF721 (NR302) was used for all L series and R-2

Table 5.4.4

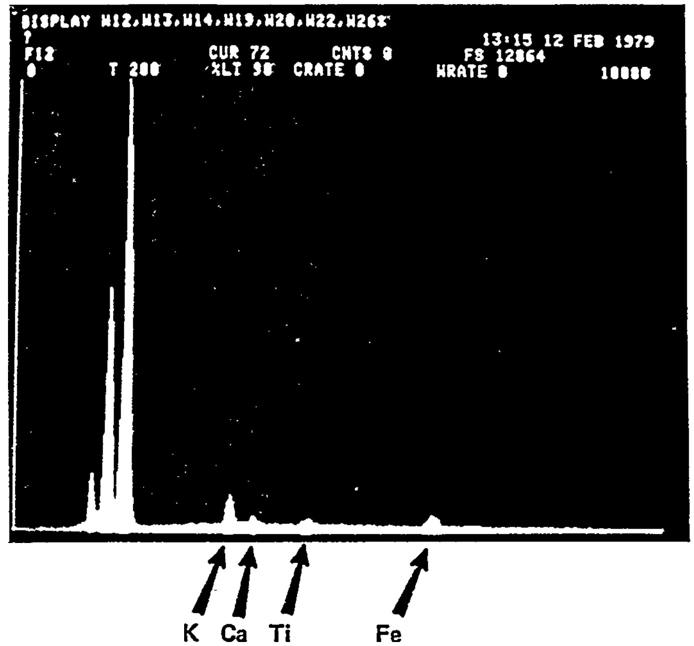
Phase IV Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti	Cr	Mo	V	CE
N-1	Root	98.442	.114	.008	.024	.896	.009	.393	.080	.006	.001	.012	.013	.002	.286
	Second	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N-2	Root	98.495	.121	.009	.033	.777	.008	.435	.089	.005	.001	.012	.013	.002	.275
	Second	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N-3	Root	98.335	.120	.010	.031	.972	.010	,409	.084	.003	.001	.012	.011	.002	.304
	Second	97.870	.090	.011	.039	1.117	.000	.705	.121	.012	.001	.015	.016	.003	.313
P-3	Root	98.252	.124	.009	.034	1.008	.007	.435	.098	.005	.001	l 012	.013	.002	.316
	Second	--	--	--	--	--	--	--	--	--	--	--	--	--	--
s-l	Root	98.384	.127	.008	.023	.933	.008	.408	.079	.005	.001	.010	.012	.002	.305
	Second	98.024	.103	.011	.030	1.062	.000	.593	.132	.010	.001	.015	.016	l 003	.312
T-1	Root	98.383	.120	.008	.023	.956	.014	.379	,084	.006	.001	.011	.013	.002	.301
	Second	98.144	.108	.011	.030	1.035	.002	.501	.127	.010	.001	.014	.015	.002	.308
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	.228
HT. #081206		98.264	.127	.018	.011	.951	.003	.376	.167	.045	.001	,020	.014	.003	.310

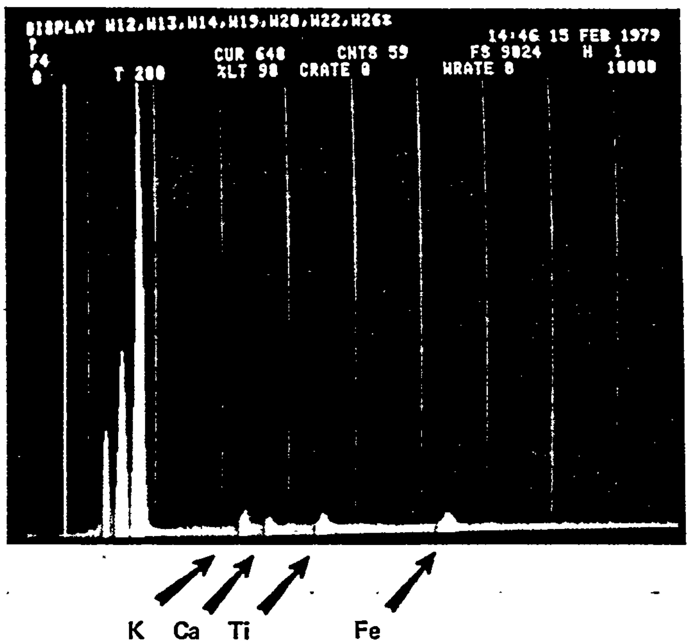
HT #081206 was used for all test coupons listed above.



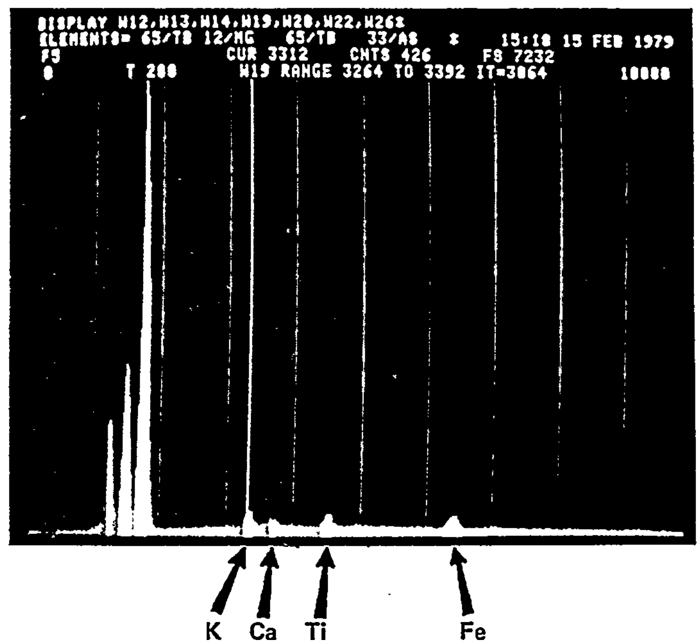
3-M TYPE SJ8069



VARIOS TYPE VLG/02



CHEMETRON TYPE 69-300000-2

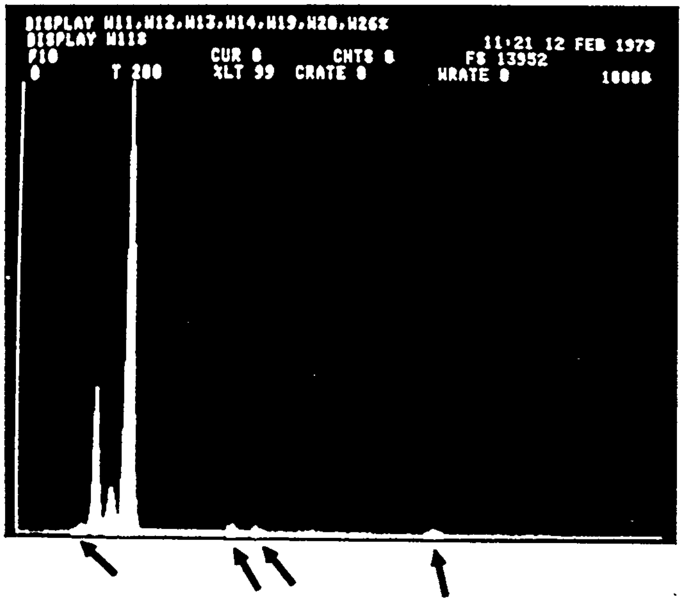


CHEMETRON TYPE 69-300000-4

TABLE 5.5

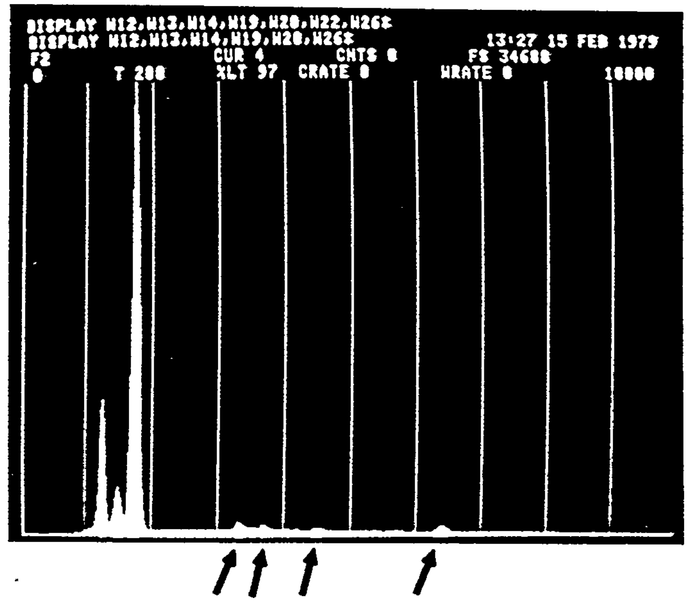
Energy dispersive x-ray (EDX) analysis of unused samples of the ceramic backing types evaluated. The horizontal scale segregates elements by atomic numbers while the vertical lines (not-to be confused with the grid lines) identifi, approximately, the relative concentrations of each element. The three major vertical lines in each photograph represent magnesium, aluminum and silicon respectively. The proportions above are indicative of cordierite. The minor elements identified individually may be from the raw material, from binders used in processing, etc.

Pg. 1 of 2



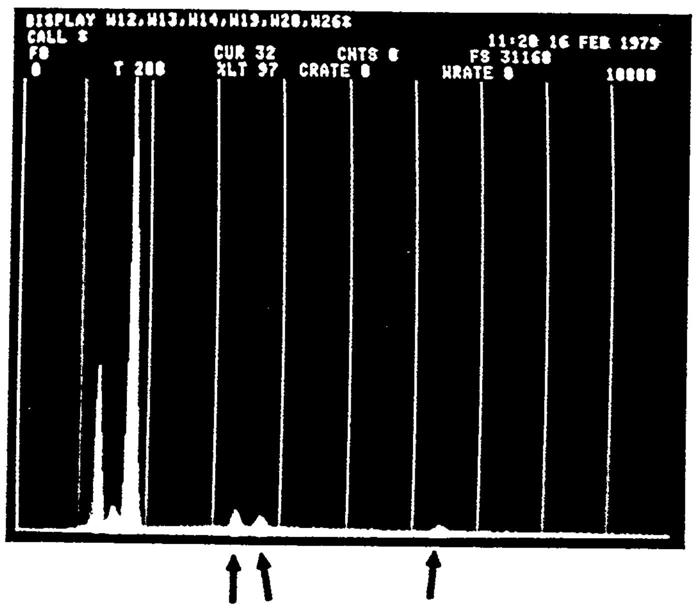
Na K Ca Fe

KUDER TYPE ICR-062



K Ca Ti Fe

KUDER TYPE 2CR-125



K Ca Fe

3-M TYPE 8J8072

TABLE 5.5 (Pg 2 of 2)

The three major vertical lines in this case are indicative of steatite.

VI. ANALYSIS OF RESULTS

VI-1 Weld Soundness

Weld soundness was evaluated by visual, radiographic, tensile and bend testing, with visual examination providing an initial screening of gross defects. Radiographic examination was performed on visually acceptable test assemblies to determine internal soundness and to screen test assemblies for mechanical testing and analysis. Transverse tensile and root bend testing verified the weld soundness assessments made by visual and radiographic examination.

No significant weld volumetric soundness problems were identified with SAW. The use of ceramic backing with FCAW, however, was occasionally burdened by internal porosity and piping comnonly described as “chevron” or “crow’s foot” porosity due to the shape and arrangement of the voids. (See Figure 6.1) When it occurs, the chevron pattern points in the direction of welding and occurs alone or with “piping” in the weld centerline area (or vice versa). The porosity voids begin between the weld fusion line and the weld centerline and terminate at or before the weld centerline. Chevron internal surfaces are smooth metallic gray with “wormhole” striations, as found in the failed, porosity-containing root bend specimen seen in Figure 6.2. The occurrence causes special concern since its presence frequently cannot be determined by visual examination of the completed root pass. Volumetric examination such as radiography is the only truly effective examination technique (Figure 6.3).

Chevron prosity and piping was found to occur only in ceramic--backed FCAW weldments in the flat and horizontal positions. It is apparently influenced by joint design, wire size, type of shielding and technique. Extensive evaluation revealed that employment of larger wire diameters with $C0_2$ shielding aggravated the problem (see Figure 6.4). For a given wire size and shielding, a 45° included angle or less tended to minimize, but not eliminate, porosity and piping tendencies. Root openings within a normal range of 5/32" to 5/16" appeared to have little positive influence concerning "chevron" improvement.

Welding technique was found to be particularly critical in avoidance of chevron porosity and piping. The backhand technique, i.e., the wire forming an acute angle with the direction of travel was found necessary. The optimum torch lead angle was found to be between 30° and 40°. Ihe arc must be directed between the center and the leading edge of the puddle. The position of the arc with respect to the puddle is a critical balance. Placing the arc at the leading edge of the puddle assured meltback of the root edges of the joint ("broom effect") resulting in a wide, smoothly contoured back bead with large reentry angles similar to a double welded joint. While such a back bead contour is desirable in its own right, existance of the broom effect appears to be a necessary condition for formation of chevron porosity and piping. By moving the arc back somewhat from the leading edge of the puddle, the broom effect is reduced and eventually eliminated, correspondingly reducing the probability of chevron porosity and piping but at the expense of back bead contour (Figure 6.5). If the arc is directed too far to the rear of the puddle, penetration and flow become retarded, causing a rough back bead with sharp re-entry angles and a less-than desirable appearance. On the other hand, if it leaves the puddle and is directed onto the ceramic, it may be momentarily extinguished due to nonconductivity of the ceramic. The underbead might then become chilled possibly causing porosity. To maintain correct arc position, visability of the puddle during welding is essential. The welder must be able to see the action of the puddle to maintain the arc at the proper location.

There are two conditions in ceramic-backed welds which, when present to a critical degree and/or combination, may lead to chevron porosity and piping. Differences in freezing patterns which exist between weld puddles solidifying over steel backing and weld puddles solidifying over ceramic backing is one condition. “This condition leads to porosity formation as illustrated in Figure 6.6 and described as follows. As solidification progresses into the puddle, bubbles are nucleated at the solid-liquid interface as dissolved gases in the liquid metal just ahead of the interface exceed their volubility in the liquid. Meanwhile, meltback of the root edges of the original joint (“broom” effect) has caused the lower portion of the solid-liquid interface to form an acute angle with the bottom of the puddle, in effect creating two “hot” regions in the puddle separated by a central region of either solidified metal or highly viscous liquid metal. If a bubble is nucleated below this central region, it is restricted to various degrees (depending on its location, the extent of meltback and the stage of solidification) from rising out of the puddle by bouyant force. Bubbles sufficiently restricted are trapped by solidified metal. Once a bubble is trapped, but before its circumference is completely solidified, subsequent surges of gas cause expansion of the bubble into the liquid portion of its periphery. Repeated trap/expansion cycles cause elongation of the voids and wormhole striations of their interior surfaces. Such expansion into the more fluid portions of the puddle accounts for the chevron/piping arrangement of the porosity. A weld made over steel backing is not divided by this viscous central region and any bubbles formed are free to break away and float out of the puddle unrestricted. Welds made in the vertical position over ceramic backing event parallel to the welding progression rather than through the solidified/more viscous region and therefore do not experience the entrapped porosity.

The second condition is the existence of more and/or different gas over ceramic-backed welds. There appears to be considerably more gas dissolved by the puddle when welding over ceramic backing than when welding over steel backing. Evidence that chevron porosity and piping is influenced by type and quantity of gases present is seen by comparing Phase I, II and III welds. Porosity and piping occurred most frequently in Phase II (CO_2 shielded), second most frequently in Phase III (self-shield, but essentially CO_2) and least in Phase I (75 Ar, 25 CO_2 shielded). The level of dissolved oxygen as a result of disassociation of CO_2 at welding temperatures into CO and O had an apparent effect.

Although the shielding gases mentioned are not unique to ceramic backing, several other sources of gas are. Moisture absorption by the ceramics due to high atmospheric humidity is a possibility. One manufacturer indicates a fair possibility of poor weld quality due to moisture absorption by their cordierite ceramic. This manufacturer recommends drying cycles of 16 hours at 110°F or 4 hours at 150°F to remove such moisture. They indicate no moisture absorption problems with steatite and suggest flame drying to remove any surface moisture. Four strips of corderite ceramic from this manufacturer were baked at 250°F for 36 hours. Two of these strips were used immediately with FCAW and C-25 shielding, one was exposed to the atmosphere for an hour and then used with FCAW and C-25, and the fourth was flooded for two minutes and dried with compressed air before using with FCAW and C-25. Upon radiographing, the two strips used immediately exhibited no porosity. The strip exposed to the atmosphere exhibited chevron porosity. The flooded strips exhibited extremely gross visual defects. To further verify absorption characteristics, water was placed on a cordierite sample. It resulted in a dramatically rapid absorption of the water followed by a similar rapid absorption of successive drops of water until a saturation point was reached. Water placed on a steatite tile, however, was not absorbed. Although water absorption by cordierite has an apparent influence, some question exists as to why porosity and piping appear to occur as frequently over steatite as over cordierite when cordierite appears to absorb water much more readily.

Another unique source of gas may be due to residual amounts of binder such as animal fat or similar material used to hold the ceramic powder together during forming and which may remain in the ceramic after baking. At welding temperatures, any such organic residuals would release such porosity-causing gases as CO_2 and H_2O. Ceramic samples rebaked for higher temperatures and times than were believed to have been used originally, resulted in welds which were radiographically clear. However, an unbaked ceramic used at the same time and with the same welding parameters was also radiographically clear.

Other sources of gas may be some reaction involving the ceramic at welding temperatures. Molten slag from the electrode may contact the ceramic backing ahead of the puddle and cause a reaction between the slag and the ceramic backing. The “broom” effect may cause extra, usually deoxidizer-short, base metal to enter the puddle reducing the deoxidizer composition below that sufficient to react with oxygen in the vicinity. Such excess oxygen may combine with carbon to form carbon monoxide gas in the weld puddle.

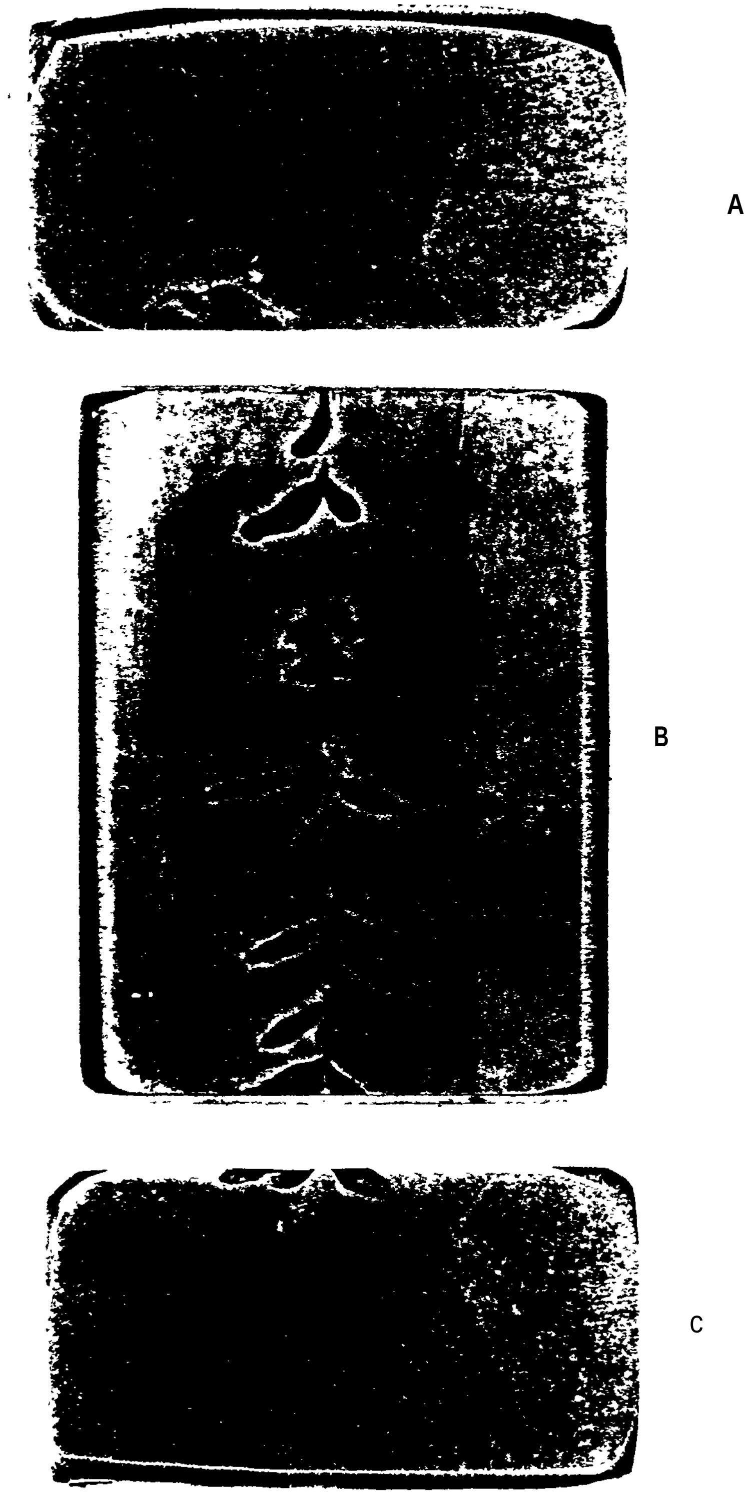


FIGURE 6.1

"chevron-type" wormhole porosity in root pass of ceramic backed weld.. Root reinforcement was ground flush to expose the porosity. Figure (a) and (c) are end views of Figure (b). Approximately 2X magnification.

FIGURE 6.2

Root bend specimen from coupon B-5-2. The portion containing chevron porosity failed while the sound portion demonstrated adequate ductility.

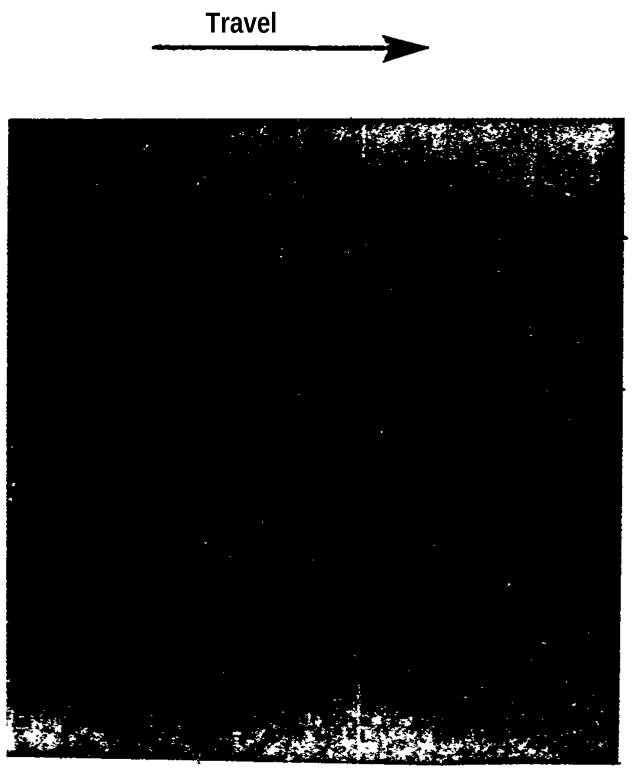


FIGURE 6.3

Chevron porosity and piping as revealed by radiography. This weldment was visually acceptable.

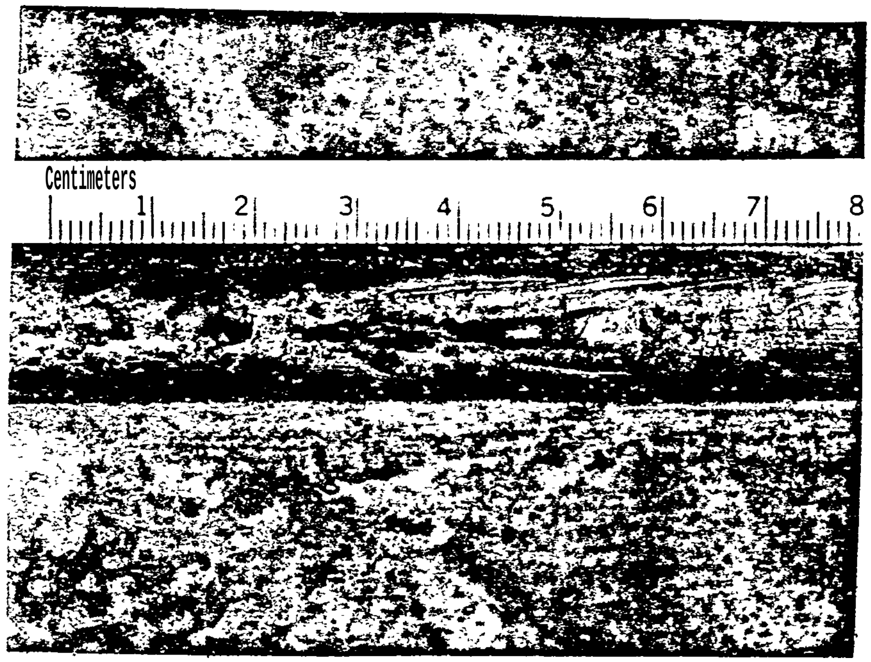
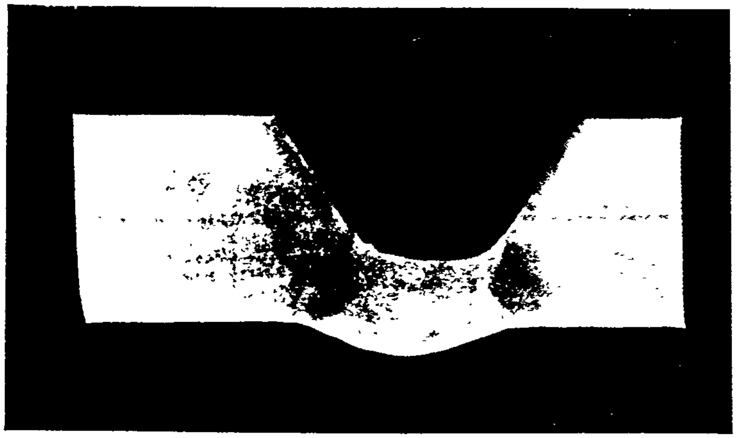
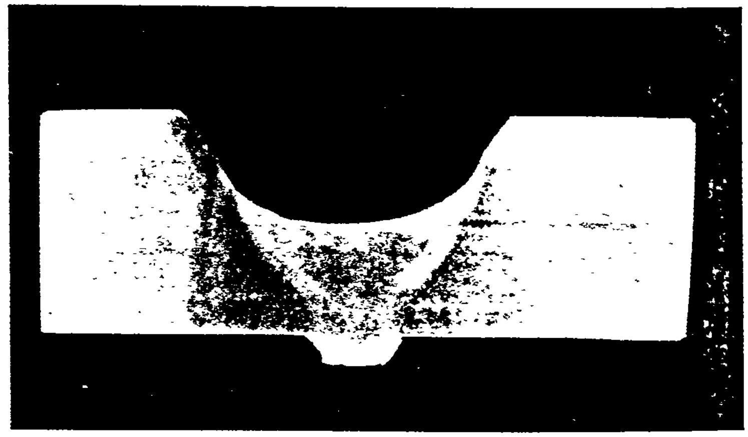


FIGURE 6.4

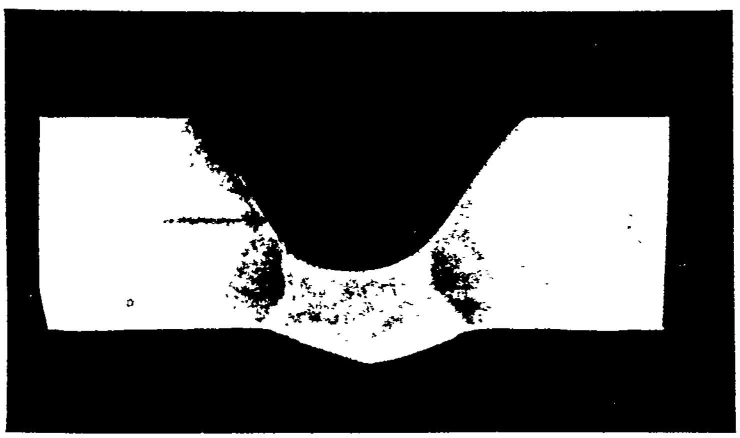
Example of gross porosity found more frequently with larger wire size and C02 shielding. This weld was made over ceramic with 3/32" Fabco-82 wire and 375 amperes at 31 volts. The joint was a 45 included angle with no land and 1/4" root gap. Flow rate was 45 CFH.



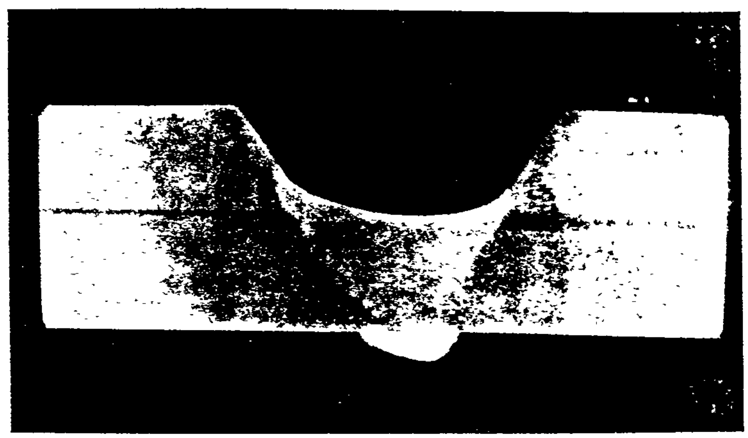
Test 1
String bead at approximately 9 IPM.
Arc at leading edge of puddle.



Test 2
Weave bead at approximately 6 IPM,
Arc at center of puddle.



Test 3
Weave bead at approximately 9 IPM.
Arc at leading edge of puddle..

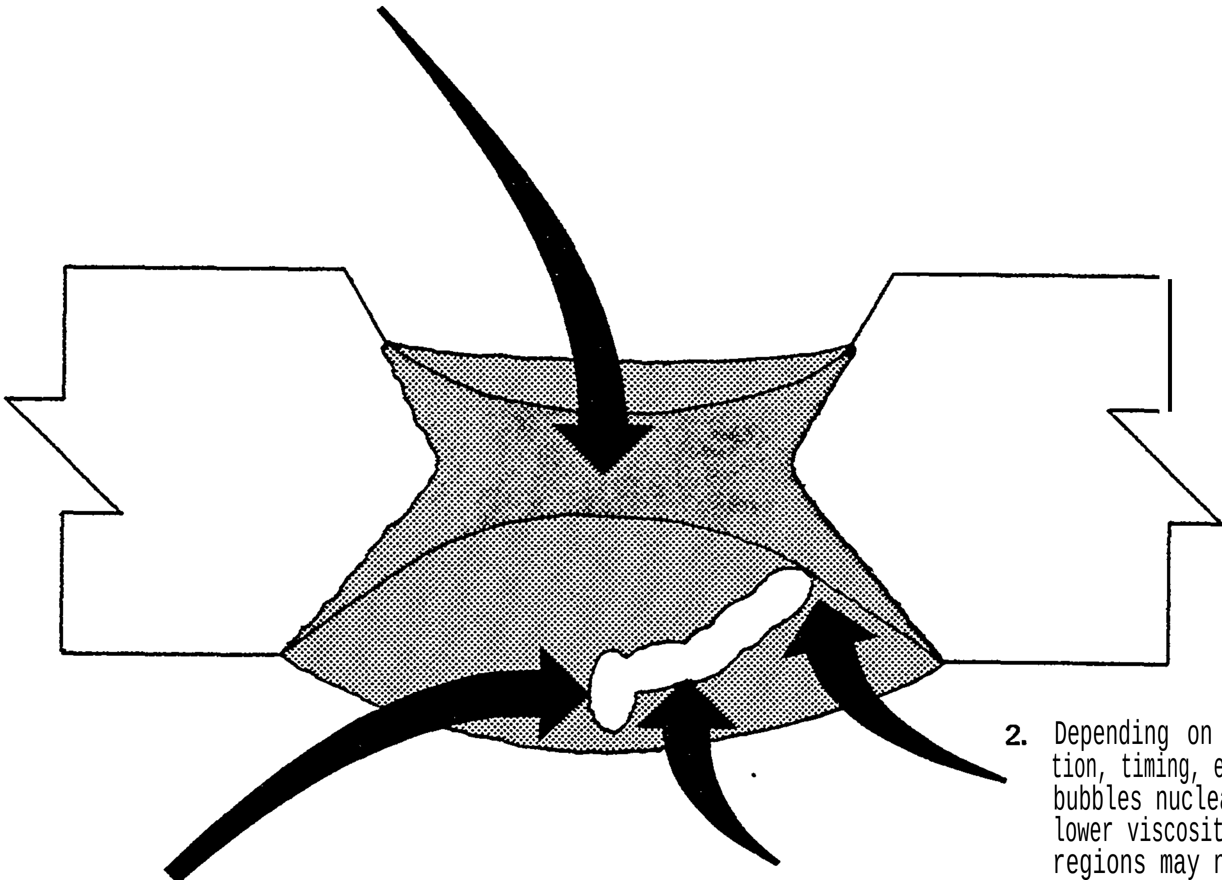


Test 4
String bead at approximately 6 IPM.
Arc at center of puddle.

FIGURE 6.5

Effect of welding technique on bead contour. All four tests were welded in the flat position with 1/16" diameter Linde FC-707 wire at 240 amperes and 25 volts. All joints were a single "vee" with 60 included angle and no land. The shielding was 75% Ar and 25% COZ at 40 CFH. The ceramic backing was 3-M type SJ8069. Root openings were approximately 3/32". Faster travel speed maintains arc to ieading edge of puddie causing meltback and broom effect. Slower travel eliminates broom effect but at expense of back bead contour.

1. Unique contour of ceramic-backed puddle causes higher viscosity across central region. A discrete region is used for illustration, viscosity actually varies continuously.



2. Depending on location, timing, etc. bubbles nucleated in lower viscosity regions may not penetrate higher viscosity regions to escape puddle.

3. Subsequent quantities of gas entering entrapped bubble cause expansion toward least resistance, i.e. toward hotter, more fluid region of puddle. Striations are due to abrupt changes in rate of gassing.

4. If gas is still released at centerline. of puddle, piping occurs with chevrons. If bubbles are not nucleated and entraped until puddle is nearly solidified, piping occurs alone.

MECHANISM FOR FORMATION
OF WORMHOLE POROSITY

FIGURE 6.6

VI-2 Toughness

Weldment toughness properties were evaluated on a representative basis. Five all-weld-metal charpy impact tests at +20°f were performed for each flat position test coupon. The test results were given in Table 5.2. The average of these five tests represents an estimate of the true toughness of the respective coupons. Since an exact value for the true toughness (as measured by impact energy) of any given coupon cannot be identified, an exact difference in true toughness cannot be identified for any pair of coupons. By using the sample data, however, a range of impact energy values having a high probability of including the true difference in toughness can be identified. Within each group, such ranges were calculated for all possible coupon pairs. The results are given in Tables 6.1.1 through 6.1.4. As an example of how this data is used, Table 6.1.1 indicates the true toughness of coupon A3 has a high probability of being from 12.7 ft. lbs. less to 8.1 ft. lbs. more than the true toughness of coupon A2. Note that in this example there may be no toughness difference at all between the coupons. As a further example, Table 6.1.1 indicates the true toughness of coupon D3 has a high probability of being from 8.9 ft. lbs. to 16.7 ft. lbs. greater than coupon D2. There is only a small chance the true toughness of coupon D3 is less than or equivalent to coupon D2.

While such an analysis identifies whether a difference in toughness is likely to exist between any pair of coupons, the magnitude of the values in Table III provides considerably more information, albeit more subjective, than just the existence of a difference. For example, Table 6.1.1 indicates the toughness of test coupon A4 (ceramic backing) is probably 8.1 to 23.3 ft. lbs. greater than test coupon Q1 (steel backing). In a given application, 8.1 ft. lbs. may not be significant while 23.3 ft. lbs. may be significant. When the comparisons are examined in this manner, it beccmes evident that differences in weldment toughness may or may not be significant depending on the relative importance of the magnitude of the trend. Some general observations, however, can be made by examination of Tables 6.1.1 through 6.1.4.

The Phase I values (Table 6.1.1) indicate a trend toward greater toughness levels with ceramic backing in Group A and a trend toward lower toughness levels with ceramic backing in Group D. Three of the four ceramic-backed coupons in Group A have greater toughness than the corresponding steel-backed coupon (Ql). Ihe Group A coupons taken together also indicate a greater toughness than the steel-backed coupon for Group A. Ihe ceramic-backed coupons from Group D, however, are exactly opposite to Group A. The ceramic-backed coupons as a composite and in three of four individual comparisons had lower toughness levels than their corresponding steel-back coupon. The greatest magnitude in any difference for either group was 29.1 ft. lbs. Such values are not excessively large especially since they represent only the upper end of a probability range. For Phase I, there is no obvious, readily evident difference in weldment toughness between coupons made with steel backing and coupons made with ceramic backing. The variations observed are too small and inconsistent to be significant and may well be due to factors other than type of backing.

The Phase II values (Table 6.1.2) indicate the steel-backed coupons being together than the ceramic-backed coupons for both Groups G and H. However, as in Phase 1, the magnitude of these differences is rather small, the greatest value for either group being only 19.6 ft. lbs. Ceramic backing was not found to influence weldment toughness in Phase II.

The Phase III values (Table 6.1.3) indicate considerable scatter. In Group I the individual range for each pair of coupons is generally tight, but there are large variations among the various ranges, some indicating very small differences and other very large differences. The individual Group L ranges are much larger than the individual Group I ranges. While there are differences of considerable or potentially considerable magnitude between ceramic-backed coupons and steel-backed coupons in Phase III, the variation in data is too great to identify any significant difference in weldment toughness between steel-backed and ceramic-backed weldments.

Table 6.1.4 indicates only very minor differences for the Phase IV (SAW) pairs. The use of ceramic backing appears to have no effect on weldent toughness for the SAW variations evaluated.

TABLE 6.1.1
ANALYSIS OF PHASE 1
TOUGHNESS DATA

DIFFERENCE	95% RANGE
A3–A2	-12.7 to +8.1
A4–A2	-13.8 to +2.4
A2 >A5	8.6 to 22.6
A3–A4	-7.1 to +13.9
A3-A5	3.6 to 23.0
A4-A5	2.8 to 17.0
A2> Q1	13.9 to 28.9
A3>Q1	9.1 to 29.1
A4>Q1	8.1 to 23.3
Q1–A5	-12.2 to +0.6
A comp.>Ql	5.1 to 21.5

DIFFERENCE	95% RANGE
D3> D2	8.9 to 16.7
D4-D2	2.0 to 11.2
D5–D2	-7.8 to +7.2
D3 >D4	1.2to 11.2
D3 >D5	6.0 to 20.2
D5–D4	-14.2 to +0.4
Q2>D2	7.9 to 15.9
Q2-D3	-5.5 to +3.7
Q2ED4	0.3 to 10.3
Q2 >D5	5.1 to 19.3
Q2>13 comp.	0.8 to 13.5

NOTES TO TABLES 6.1.1,6.1.2,6.1.3 AND 6.1.4

1. "95% range" means the range having a 95% probability of including the true difference in impact energy for each pair of coupons. 95% is an arbitrarily selected high probability since a 100% range would extend from minus to plus infinity and would therefore be meaningless.
2. An arrowhead indicates the coupon on the left has greater impact energy than the coupon on the right. A dash indicates no significant difference in impact energy could be found.
3. "Comp." means the data for the ceramic-backed coupons was taken as a group (composite) and compared to the steel-backed coupon. The "Comp." comparison attempts to preclude any difference which may be due to the brand or type of ceramic.

TABLE 6.1.2
ANALYSIS OF PHASE II
TOUGHNESS DATA

DIFFERENCE	95% RANGE
H2-HI	-4.7 to +2.5
HI-H3	-0.9 to +4.7
H2-H3	-2.5 to +4.1
Q4>Hl	7.1 to 13.5
Q4>H2	7.7 to 15.1
Q4>H3	9.3 to 15.1
Q4>H Comp.	8.9 to 13.7

	DIFFERENCE	95% RANGE
*	(G1>G2	1.6 to 6.8
	G3-G1	-7.6 to +0.2
*	G2 >G3	9.1 to 17.7
	Q3>GI	3.4 to 14.2
*	Q3>G2	6.4 to 19.6
	Q3>G3	6.6 to 18.4
*	Q3>G comp.	8.2 to 14.4

*The value 80.5 ft. Ibs. for G2 was omitted in calculations due to gross inconsistency with the other four G2 data points.

TA3LE 6.1.3
ANALYSIS OF PHASE Ill
TOUGHNESS-DATA

DIFFERENCE	95% RANGE	DIFFERENCE	95% RANGE
1243	15.4 to 17.4	L2-L3	-10.5 to +16.1
12>14	31.7 to 33.7	L4-L2	-28.8 to +3.6
12>15	1.9 to 3.9	L5-L2	-6.1 to +22.5
13 >14	15.3 to 17.3	L4-L3	-25.7 to +6.1
15>13	12.5 to 14.5	L5-L3	-3.0 to +25.0
15>14	28.8 to 30.8	L5>L4	4.1 to 37.5
12-R1	-34.5 to +31.7	R2-L2	-23.3 to +8.9
R1 >13	16.8 to 18.8	R2-L3	-20.3 to +11.5
R1 >14	33.1 to 35.1	L4-R2	-23.7 to +12.9
R1>15	3.3 to 5.3	R2-L5	-32.1 to +1.3
I comp.-Rl	-34.5 to 5.7	R2-L comp.	-18.1 to +7.3

TABLE 6.1.4
ANALYSIS OF PHASE IV
TOUGHNESS DATA

DIFFERENCE	95% RANGE
N2-N1	-4.1 to +5.3
N1-N3	0.7 to 11.2
N2-N3	0.7 to 12.5
N1-S1	0.7 to 9.9
N2-S1	0.3 to 9.9
N3-SI	-6.7 to +3.7
N comp. - S1	-1.9 to +7.3

VI-3 Bead Shape

The test coupon back beads were examined for amount and contour of reinforcement and for re-entry angles. Figure 6.7 identifies these attributes along with the two bead shape problem categories encountered when using ceramic backing. An optimum bead shape exhibits large, smooth re-entry angles and a moderate, smoothly-contoured rcement. Such a bead shape was typical of the FCAW test coupons for this evaluation as seen in the macrophotographs (Figure 6.8).

The Phase I, II and III (FCAW) test coupons were welded with the arc directed at the leading edge of the puddle, a technique resulting in melback of the root edges of the joint creating a bead contour similar to a double-welded joint. By moving the arc back toward the center of the puddle, less meltback-"broom"-effect is obtained, but, as discussed in the section on weld soundness, at the expense of bead shape. The FCAW welding technique must strike a balance between-optimum bead shape and the chance of incurring excessive back bead sag and/or chevron porosity.

While the broom effect results in the optimum bead shape described above, it also contributes to back bead sag and to chevron porosity. Ihe mechanism for its creation is described as follows. Heat flow away frcm the puddle is much slower through ceramic backing than through steel backing. (Thermal conduc-activity of cordierite for example, a common ceramic backing material, is .0077 cal/(see.) (cm^2) (°C/cm) at +20°C. Thermal conductivity for a low carbon steel at +20°C is .12 cal(sec.) (cm^2) (°C/cm). Ihermal conductivity for the steel is approx-imately fifteen times greater.) Heat which would normally flow away from the puddle through steel backing material enters the base material instead when welding is performed over ceramic backing. This concentrated heat flow (probably combined with a somewhat higher current density in this region since a nonconductor has been inserted in part of the original current path) melts the edges of the base material adjacent to the ceramic to a much greater depth than a corresponding joint with steel backing would be melted. This flare back ("broom") effect is readily evident in the macrophotographs of ceramic-backed weldments made with FCAW. It does not occur with the large, fluid SAW puddles.

Low spots(undercut when the surface of the back bead lies below the base metal plane) sometimes occurred with Phase I weldments in the horizontal position as a result of back bead sag. The mechanism of back bead sag is inherently 1 imited to weld joints in the horizontal position due to the asymetrical effects of gravity in that position as seen in Figures 6.9.1 and 6.9.2.

Back bead sag occurs when the enlarged molten weld puddle on the back bead side tends to assume a teardrop shape, settling onto the lower base metal edge. Although this sag usually only causes greater reinforcement at the bottom of the back bead than at the top, the resulting reduced volume of material at the upper base metal edge, combined with shrinkage of the cooling solidified puddle (there is no bond to the ceramic backing material and, therefore, no lateral restraint to shrinkage stresses) , may cause a portion of the upper back bead to lie below the plane of the base metal surface.

When meltback is especially severe on the upper plate edge, a "keyhole" condition will occur on the top root edge adjacent to and ahead of the puddle. (See Figure 6.10) . As a result, a slower travel speed is necessitated to fill the burn-away area since travel speed over ceramic backing is limited by the fill rate of the puddle. This compounds the problem, however, by producing excessive back bead reinforcement and even more burn away, in turn causing additional sagging at the top of the back bead. In conjunction with a lead angle of approximately 30°, a slight work angle of 5-15° was normally found to aid in tying in the upper plate. This work angle, however, further aggravates the burn-away problem when it occurs by directing the arc onto the upper plate edge.

Variations in weld joint dimensional parameters were found to have a significant effect on the weld metal sag problem. A 60° included angle tended to aggravate the sag apparently because of the thinner root edge than with say a 45° included angle. Using a 45° included angle (22 1/2° bevel on the upper plate edge) and limiting the root gap to 5/32" maximum (1/8" optimum) resolved the problem. The thicker edge due to the smaller bevel causing less meltback, together with the narrower root gap, reduced the vertical dimension identified in Figure 6.9.1 to such an extent to eliminate undercut, if not sag. The low spot/undercut problem did not recur with self-shielded wire in the horizontal position (Group J) due to the fast-freeze characteristics of the wire.

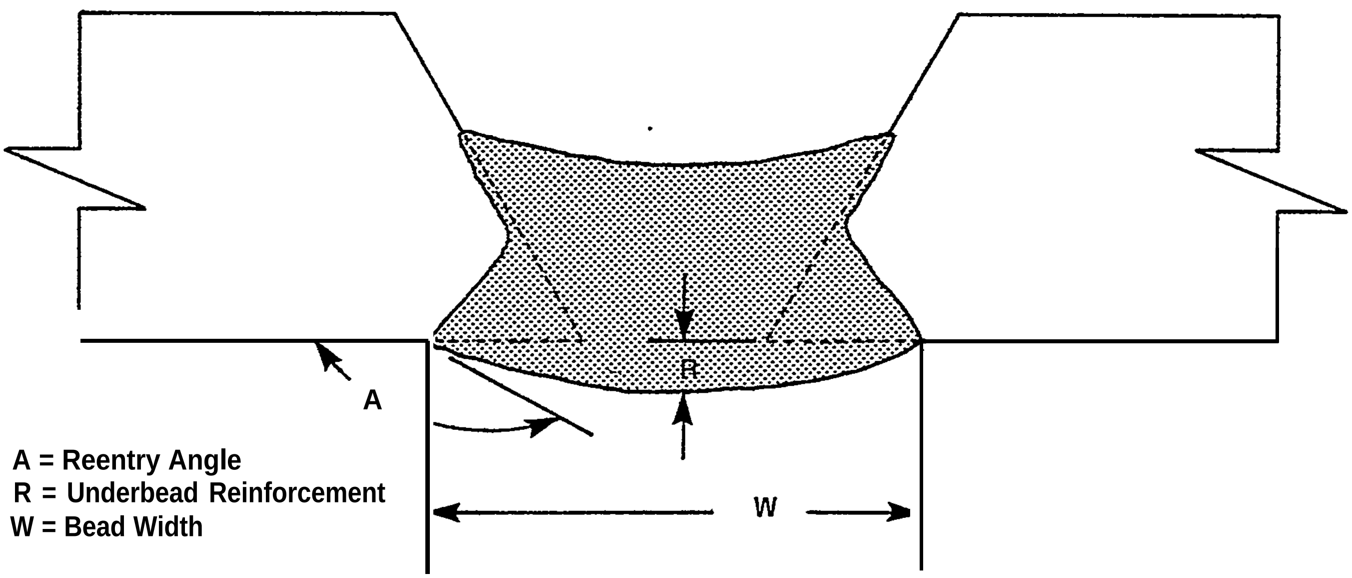
The second problem category, finning (Figure 6.11. 2), was found in Phase IV evaluation, only occasionally with single wire submerged arc but frequently with tandem submerged arc. Finning is equivalent to flash in a casting operation in which molten metal is unintentionally extruded into voids or crevices in the pattern. It occurs in ceramic-backed weldments when a critical combination of puddle fluidity and ceramic/joint geometry make it occur before the desired reaction in which contact with the molten puddle melts areas of the ceramic which then conform to and shape the back bead contour. The surface to volume ratio of the fins is too large for heat flow at any point on the surface of the fin to melt either ceramic or base metal which it contacts.

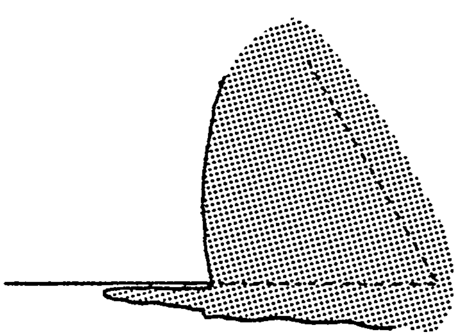
With single-wire submerged arc finning occured with the larger Chemetron ceramic, the ceramic havinq the widest groove; Kuder and 3-M ceramics provided satisfactory results. Travel speed had a distinct effect on bead shape and control of the underbead reinforcement. Excessive travel speed produced a shallower penetration with a very narrow and occasionally intermittent underbead with areas of lack of penetration. A travel speed too slow resulted in complete consumption of the root land, but excessive back bead reinforcement and occasional finning due to increased fluidity at the root of the puddle. A workable range of parameters was identified, however, indicating there should be few problems adapting single wire submerged arc to ceramic backing.

Although marginally acceptable parameters were established for the smaller Chemetron ceramic using tandem submerged arc, parameters could not be identified which would consistently result in an acceptable back bead. Welding parameters, especially travel speed, appeared more sensitive with tandem than with single-wire submerged arc. Because the tandem submerged arc puddle is two to three times the size of the single-wire submerged arc puddle and therefore more fluid, finning occurred before the ceramic could melt and shape the bead contour. Tandem submerged arc does not appear to be adaptable to ceramic backing.

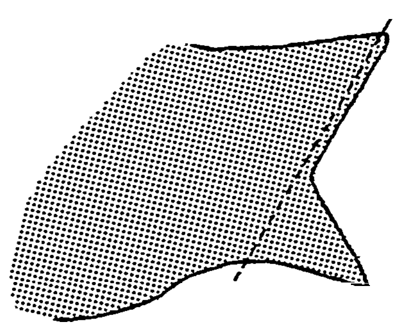
FIGURE 6.7

GEOMETRIC ATTRIBUTES OF BACK BEAD AND PRINCIPLE DEFECTS





Finning
(Found with SAW Weldments)



Low Spot/Undercut
(Found with Horizontal FCAW Weldments)

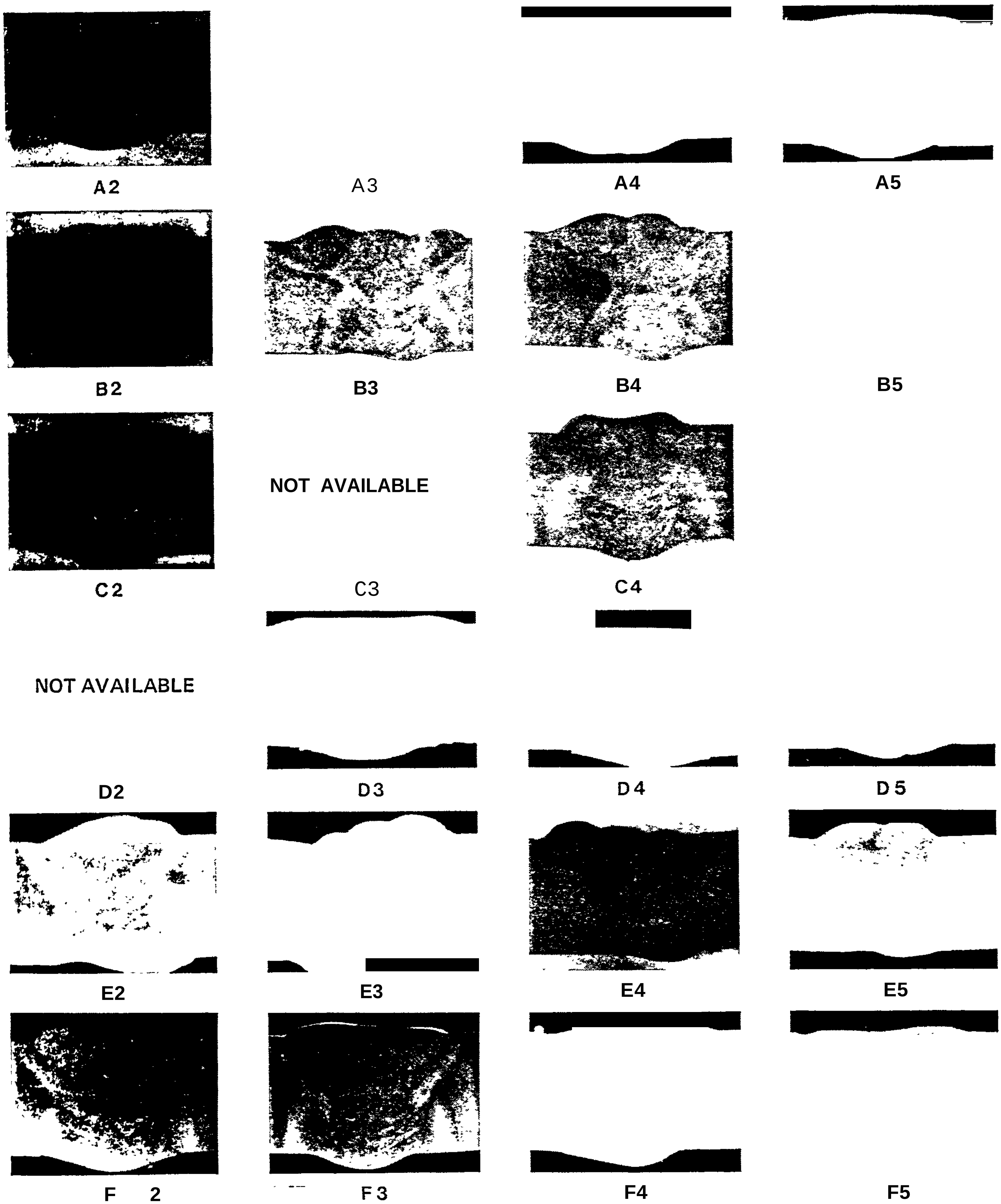


FIGURE 6.8.1

Cross-Sectional Macrophotographs of Test Coupons

PHASE 1

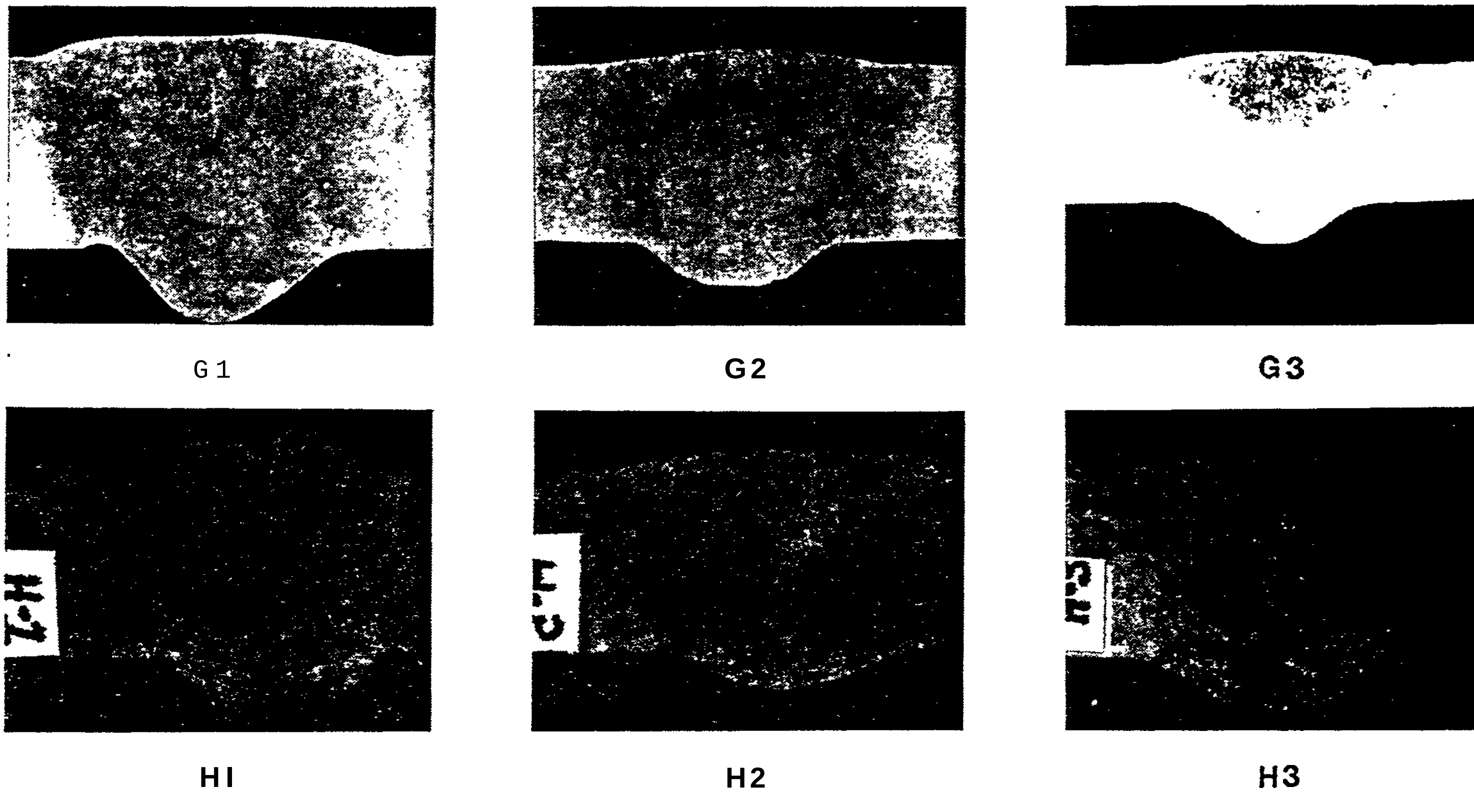


FIGURE 6.8.2

Cross-sectional Macrophotographs of Test Coupons

PHASE II

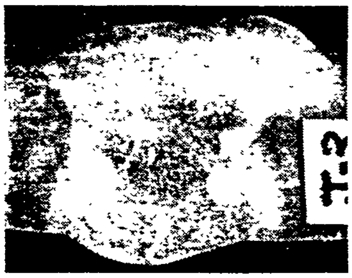

I2


I3

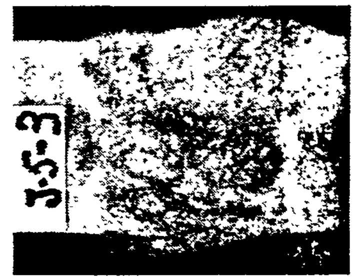

I4


I5


J2

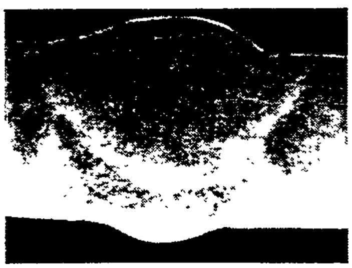

J3


J4

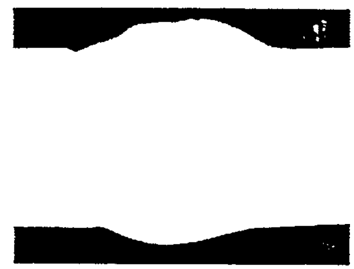

J5

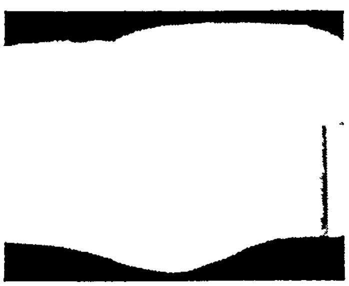
NOT AVAILABLE

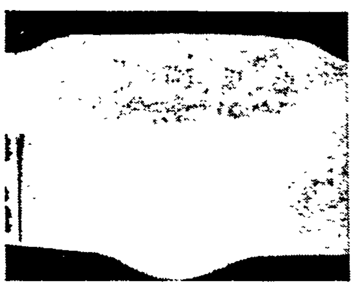
K2


K3


K4


K5


L2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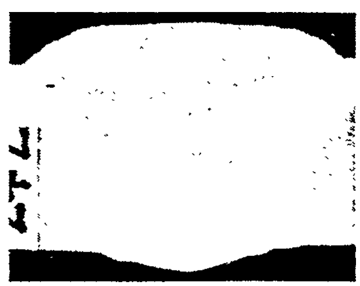
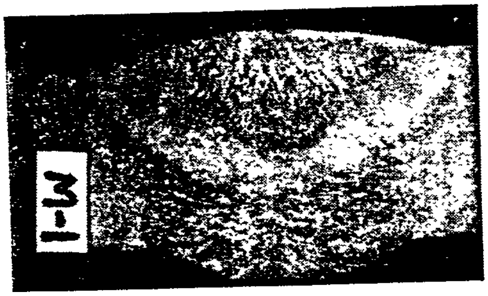

L4


L5

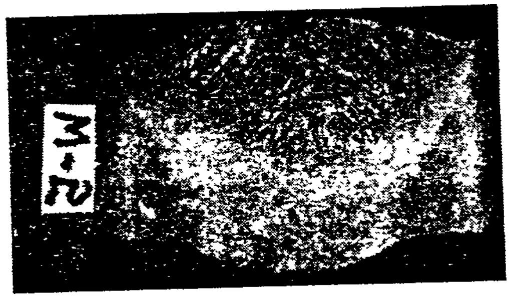
FIGURE 6.8.3

Cross-Sectional Macrophotographs
of Test Coupons

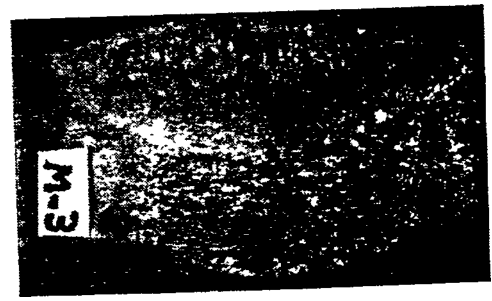
PHASE III



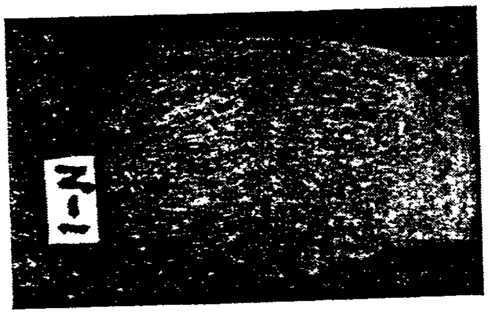
M1



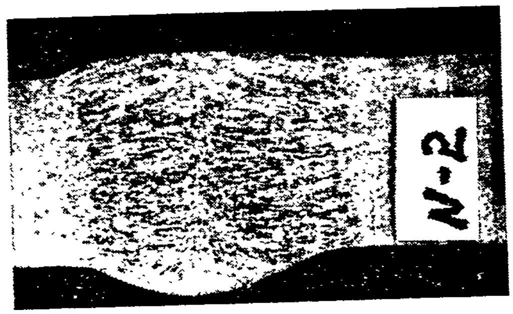
M 2



M 3



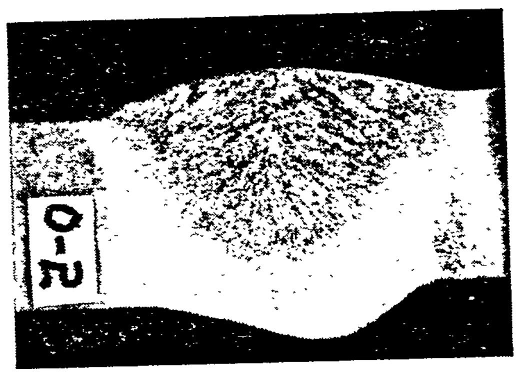
N1



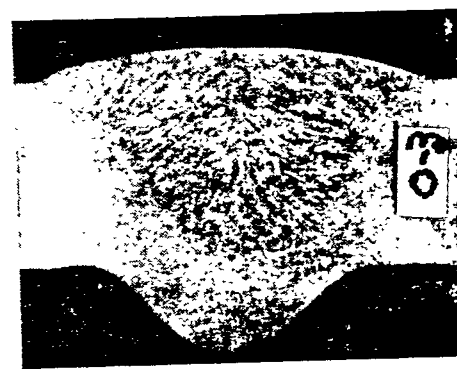
N 2

N 3

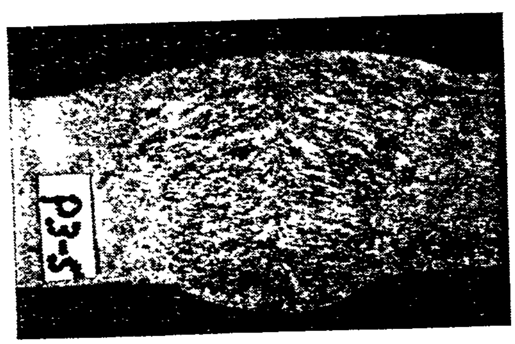
01



0 2



0 3



P3

FIGURE 6.8.4

Cross-sectional Macrophotographs of Test Coupons

PHASE IV

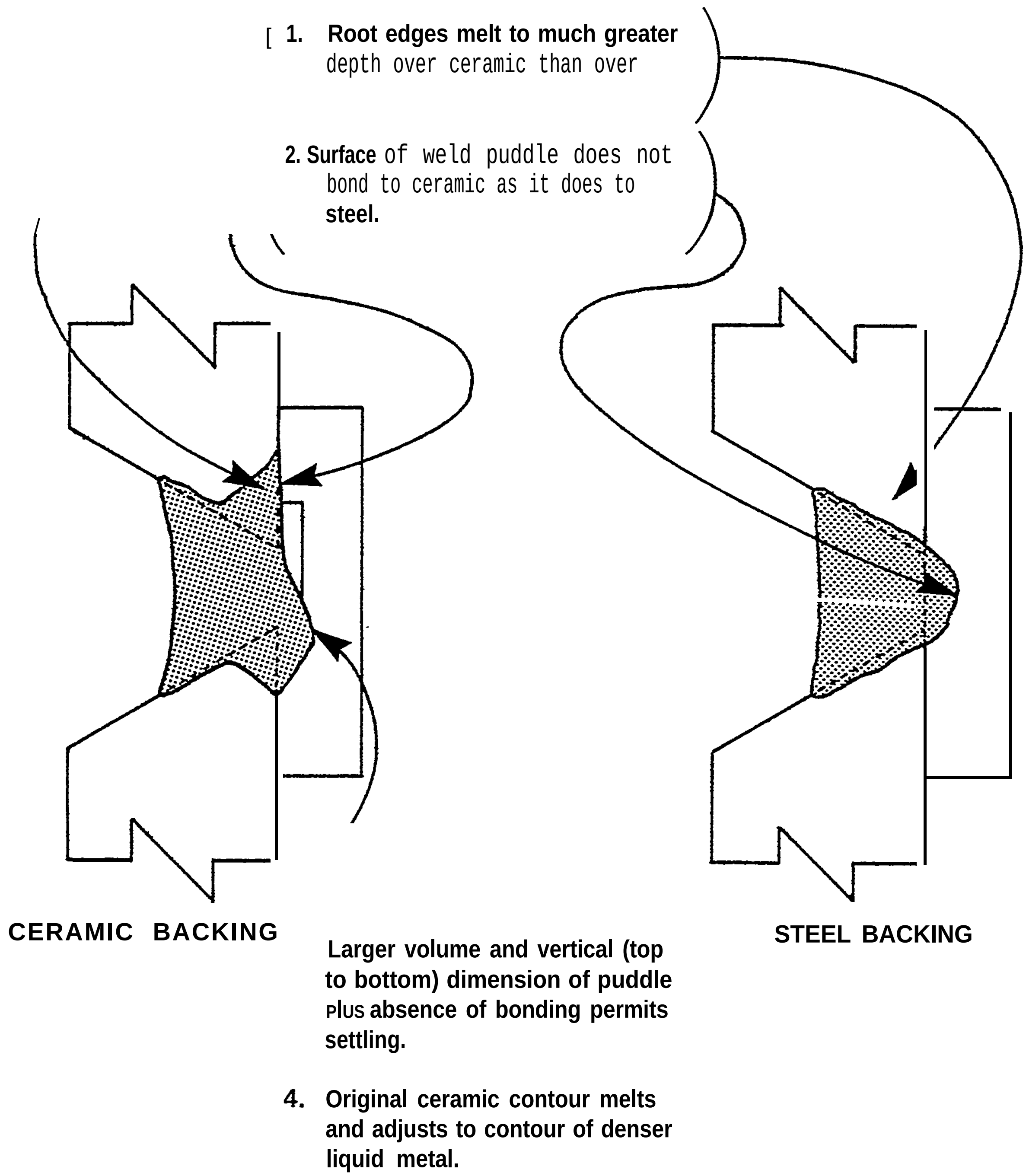


FIGURE 6.9.1

MECHANISM OF WELD METAL SAG WITH HORIZONTAL FCAW

FIGURE 6.9.2 .

Examp!e of undercut along top toe of the back bead due to gravity-induced sag of the molten puddle in the horizontal position.

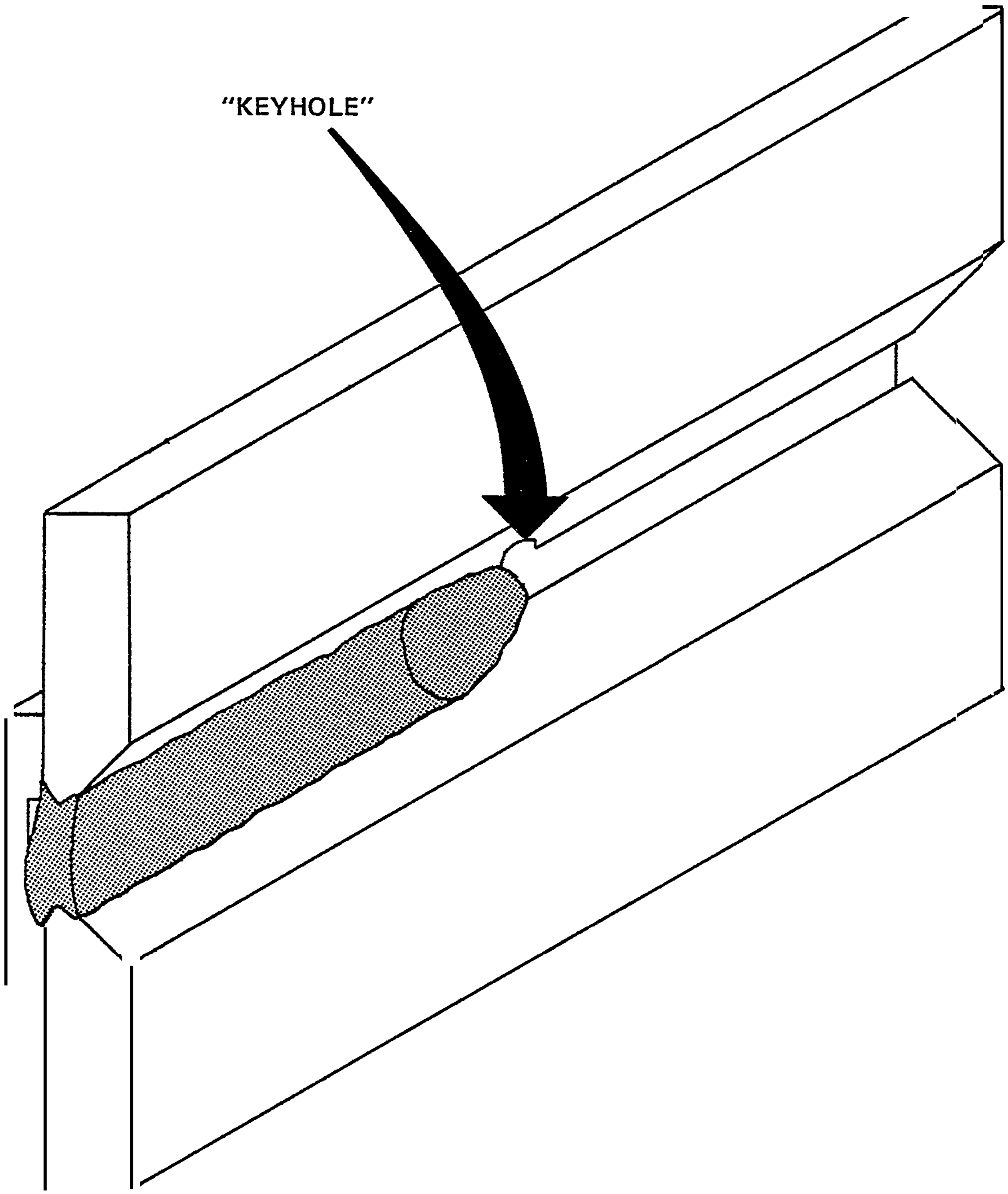


FIGURE 6.10

UPPER LAND BURNAWAY "KEYHOLE" AS IT APPEARS TO WELDER, INDICATING A HIGH PROBABILITY OF BACK BEAD SAG RESULTING IN LOW SPOTS/UNDERCUT

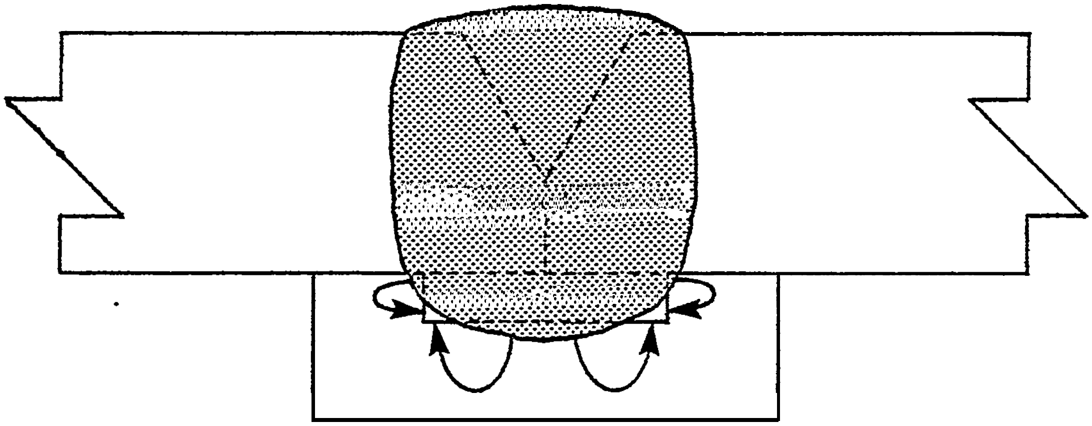


FIGURE 6.11.1

Desired reaction of ceramic-backing/weld-puddle system. Ceramic melts and flows under weight of puddle, as indicated by arrows, adjusting to and contributing to contour of back bead.

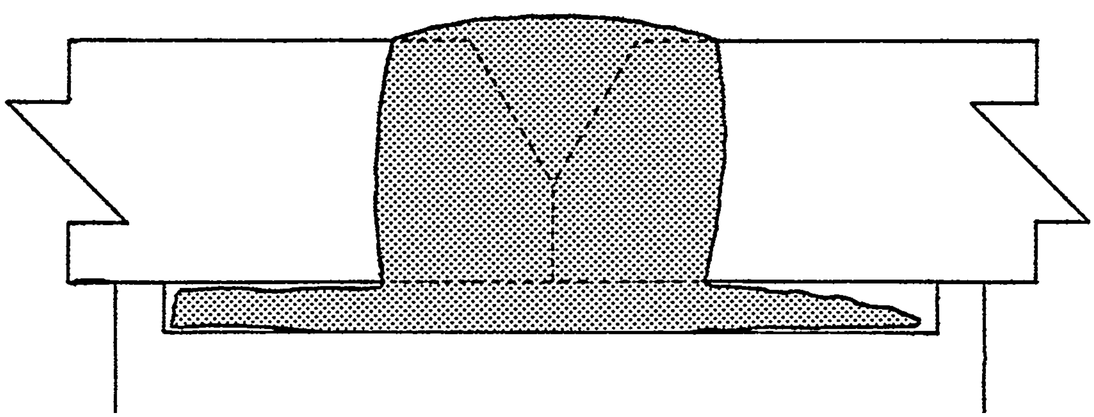


FIGURE 6.11.2

As width of groove is increased and/or puddle becomes more fluid, the weld metal may extrude into the void without melting the ceramic.

VI-4 Stops and Starts

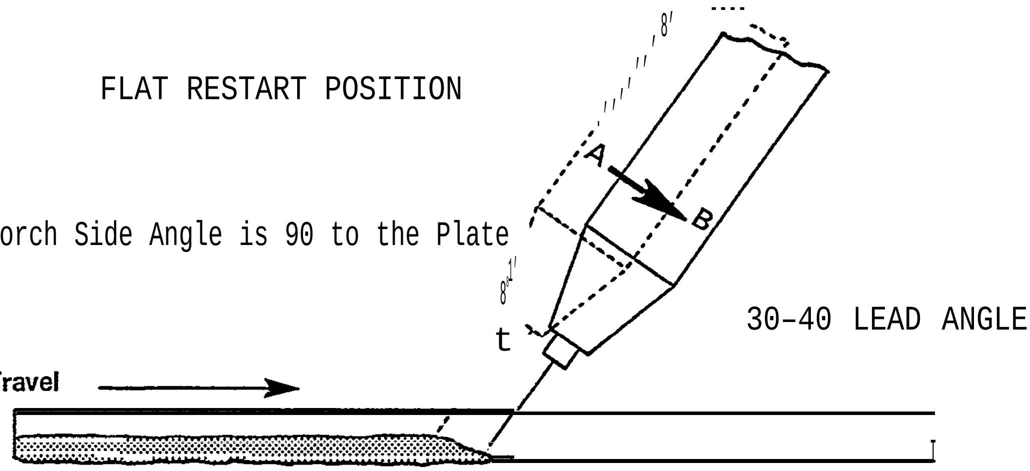
Welding techniques to accomplish sound starts and stops were evaluated. Two techniques were employed in stop and restart evaluation for FCAW. See Figure 6.12. Both techniques were evaluated in the flat, horizontal, and vertical position. The first technique was simply breaking the arc, removing the slag in the crater area, hand wire brushing and re-establishing the arc. The second technique was a variation on the first. A small pneumatic grinder was used to grind a ramp in the crater area to reduce the metal thickness and to facilitate complete fusion and penetration of the stop area of the previously placed bead. When employing either of the techniques, it was found necessary to start the arc at the rear of the existing crater, bring it immediately forward to the desired location, and briefly hold at that point to ensure complete penetration and back bead build up. Prior to proceeding along the joint when making the restart, the lead angle should be the same as when welding the joint; i.e., 30-40°. This allows for complete break-down of the crater leading edge and a more uniform back bead at the restart. It was found that a more uniform restart and underbead in the restart area could be obtained with the second technique.

Unplanned stops and starts should be avoided with SAW over ceramic backing. When welding was stopped, the ceramic moved slightly away from the root of the joint. To properly replace the ceramic under the restart area, the back bead reinforcement had to be ground sufficiently for the new ceramics to fit flush to the base metal for a short distance back from the restart area.

FIGURE 6.12
FCAW RESTART TECHNIQUE OVER CERAMIC BACKING

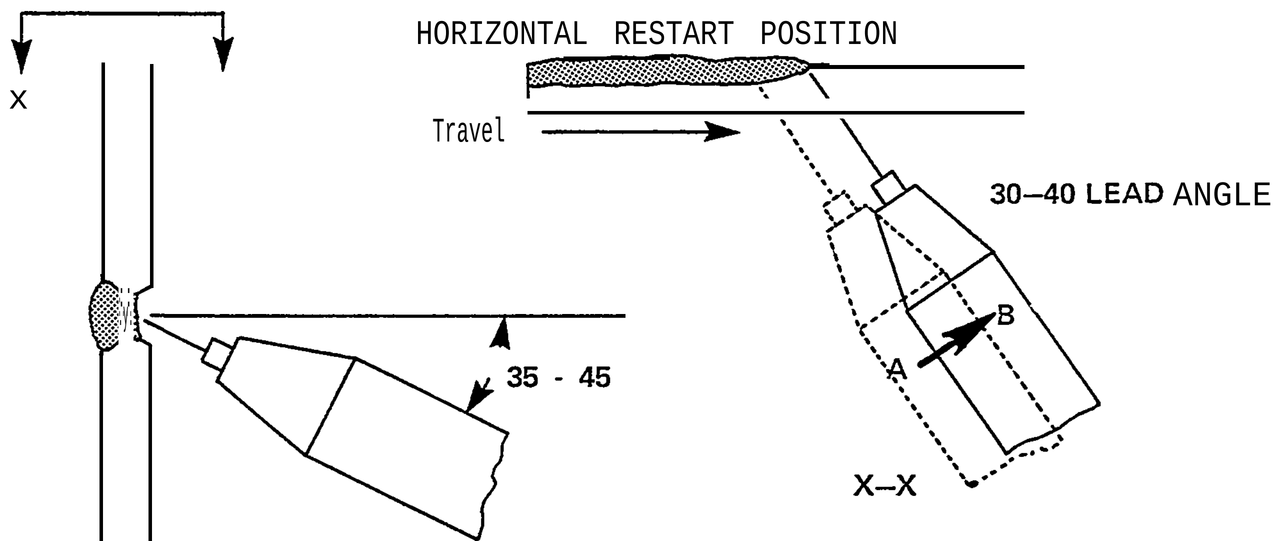
FLAT RESTART POSITION

Torch Side Angle is 90 to the Plate



Arc is established at Position "A", and brought immediately forward to the lead edge of the crater, Position "B".

HORIZONTAL RESTART POSITION

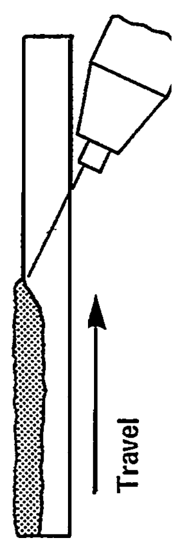


Arc is established at Position "A".,-and brought immediately forward to the lead edge of the crater, Position "B".

VERTICAL RESTART POSITION

65-75 LEAD ANGLE

Torch Side Angle is 90 to the Plate



Arc is established at the lead edge of the crater.

VI-5 Ceramic Attaching Methods

The adhesive effectiveness with regard to position, surface cleanliness and surface temperature was evaluated. Some difficulty occurred, especially at elevated temperatures and on scmewhat less than clean contact surfaces, with adhesion of the tape which holds the ceramic bcking in place especially when the contact surfaces had an as-received coating of mill scale or a coating of shop dust. Abrasive blasting of the contact surfaces and wiping of the surfaces just prior to placing the tape appeared to provide satisfactory adhesion. Evaluations were made in the flat, horizontal and vertical positions and with the test plates in the following conditions of cleanliness; (1) as-received (rust, mill scale, etc.), (2) power wire brushed, (3) ground, (4) abrasive blasted, and (5) abrasive blasted and wiped with a dry cloth just before assembly. The best adhesion was obtained when abrasive blasting and wiping of the base material were used together.

The adhesive was evaluated at base material temperatures ranging from 45° to 450°F. At the higher temperatures, adhesion was far less than at lower temperatures. At higher temperatures, the adhesive sometimes loosened permitting the ceramic backing to fall away from the base material resulting in excessive reinforcement on the back bead when the molten puddle tried to fill the space. The adhesive appeared to break down above approximately 400°F. One manufacturer advised that their adhesive was designed to do so to assist in removal after welding. The three tapes evaluated for adhesiveness were Chemetron, Kuder, and 3-M. Little difference was noticed.

The practicality and adpatability of magnetic holding devices to a construction environment were evaluated. The devices evaluated were manufactured by Varies and were used with other Varies materials. In all combinations the magnetic devices held the ceramic backing securely in place and firmly to the base material eliminating a possible cause of excessive reinforcement and producing a good back bead. The magnetic devices also resulted in a much cleaner environment, since smoke and color produced when heating the adhesive were eliminated.

One problem with the magnetic devices, however, was loading the ceramics into the support sections. The ceramics, are not completely uniform in size when manufactured. Athough most ceramics fitted nicely into the support section and functioned as designed, some were so loose that once inserted into the support section and positioned on the base material, they fell out. Still others were too large to be inserted into the support sections without bending the section sides out to accommodate them. This caused the pieces that previously fit to become loose. Holding devices with the ceramic tiles already in place are available and are recommended. No surface cleaning or other special preparation was necessary with the magnetic holding devices. Temperature had no apparent effect on the function of the devices.

VI-6 Ceramic Neutrality

The ceramic backing chemical composition and deposited weld metal root and second pass diluted composition were evaluated using an energy dispersive x-ray analytical system and spectrographic system respectively. Results of the spectrographic analysis of the deposited weld metal were given in Table 5.4. Results of the x-ray analytical system analysis of the ceramic backing were given in Table 5.5. Although base metal heat number identification was not maintained, the typical analysis in Table 5.4 approximates the Composition of the A36 base metal used. The weld metal composition data points are leveled across a 5/16" diameter area in the Spectrovac II system used and hence may or may not represent a homogeneous distribution of a specific element. For example, a weld metal surface in which the silicon composition of the matrix is .3% might hypothetically contain particles of SiO_2 totaling 3.8×10^{-4} square inches (.5% of the total area.) The silicon composition identified by spectrographic analysis will then be .53% (.003 (.995) + .467 (.005) = .0053/SiO_2 is 46.7% Si by weight).

Ceramic neutrality was defined as any change in weld metal composition due to use of ceramic backing. Ceramic backing may possibly alter the weld metal composition directly by some chemical reaction within the weld puddle envirornment or by contributing entrapped ceramic particles to the weld metal. It may also indirectly alter the weld metal composition by changes in dilution ("broom" effect) or by preventing escape of material which would normally escape a steel-backed weldment.

Theoretically, one way in which ceramic backing may directly affect the weld metal composition is by contributing products of reduction of aluminum, silicon and magnesium oxides of which the ceramic is composed. Since aluminum, silicon and magnesium all have a much greater affinity for oxygen throughout the prevailing temperature range than potential reducing agents in the puddle environment, however, the likelihood of such a reaction is remote. Direct contributions of material from ceramic particles themselves is much more likely to occur than reduction of ceramic oxides. Since any larger particles present would have been identified by volumetric examination, any particles in the coupons analyzed would be very fine. Such particles would represent a localized high concentration of the ceramic compo sition (aluminum, silicon and magnesium).

In addition to any direct effects of ceramic backing, indirect effects on weld metal composition may result from changes in dilution and weld metal viscosity due to the "broom" effect which occurs with most FCAW ceramic-backed weldments. Change in weld metal viscosity may lead to entrapment of certain elements which would usually escape. Weld metal composition is normally affected by oxidation and float-out of certain elements in the puddle, the necessary oxygen resulting from disassociation at welding temperatures of carbon dioxide shielding gas into carbon monoxide and oxygen. Oxidation and float-out may be inhibited by changes in puddle contour and/or viscosity due to ceramic backing.

To help determine whether any of these possible events actually occurred, the data from Table 5.4 for the deposited root beads is graphically displayed in Table 6.2. Table 6.2 was constructed by plotting vertically, for each group and each element, the difference between the root bead analysis for each ceramic-backed coupon and its corresponding steel-backed coupon. Points above the horizontal (zero) line indicate, for the specific coupon and element, a higher composition for a ceramic-backed coupon than for its corresponding steel-backed coupon and vice versa. For each group except D the same wire heat was used throughout. Since processes, shielding, wire heats, etc., are essentially the same for each comparison, any significant variation can be attributed to ceramic backing.

Since the "broom" effect and oxidation loss does not occur to any appreciable extent with SAW, differences in composition between ceramic-backed and steel-backed weldments would be expected to be rather small if there are no direct effects from ceramic backing. The differences identified by Table 6.2 for SAW (groups N and P) are small or do not exist for most of the elements. Accordingly, for SAW there appears to be no significant direct or indirect effect on weld metal composition due to use of ceramic backing.

For FCAW, a trend toward increased silicon content for ceramic backed versus steel-backed weldments when using CO_2 or self-shielded wire is identified. This trend is likely the result of entrapped particles of SiO_2. The fact it occurs only with the processes having higher shielding oxygen content is a strong indication the particles result from oxidation and subsequent entrapment of silicon in the puddle. Entrapment of particles of ceramic backing would be expected to occur equally with all the FCAW processes since puddle contour and viscosity is similar for all FCAW ceramic-backed weldments. The oxidation and entrapment mechanism is more likely to produce the fine, dispersed particles necessary to escape identification by volumetric examination, providing another indication the higher silicon is not due to direct contribution by the ceramic backing.

Manganese in the weld puddle combines first with any sulfur present forming Mns which tends to float out of the puddle. Some remaining manganese may react with any oxygen remaining after silicon and/or aluminum react with it first. Any Mno thus formed immediately reacts with carbon, forming metallic manganese and carbon monoxide (This reaction may contribute to the soundness problems discussed in Section VI-l). This manganese, plus any which did not react with oxygen or sulfur, forms Mn_3C which is indistinguishable from Fe_3C and remains in the weld, having formed after solidification. Although some Mns may become entrapped in the same manner as SiO_2, the quantity of Mns is too small to identify any trends on the basis of sulfur. A possible but vague trend toward lower manganese content with FCAW andceramic backing can be attributed to increased dilution obtained from the "broom" effect, the base metal being consistently lower than the wire in manganese. An increased-dilution type analysis for FCAW over ceramic backing also tends to explain the variations in nickel and titanium content.

In summary, there was no evidence found to indicate that ceramic backing contributes directly to the composition of either or SAW weldments with which it was used. Of the three elements, the oxides of which are the principle constituents of the ceramic backing evaluated magnesium could not be evaluated with spectrographic techniques; no trend, either higher or lower, could be identified for aluminum; and the trend toward increased silicon could be adequately explained by other than direct contribution from the ceramic backing. There were some mild indirect effects on weld metal composition due to use of ceramic backing with FCAW. These effects are probably caused by increased dilution at the root of the joint and resultant changes in viscosity distribution of the molten puddle, i.e., they are due to the "broom" effect. These changes should have little or no effect on the performance of a sound weldment made with ceramic backing.

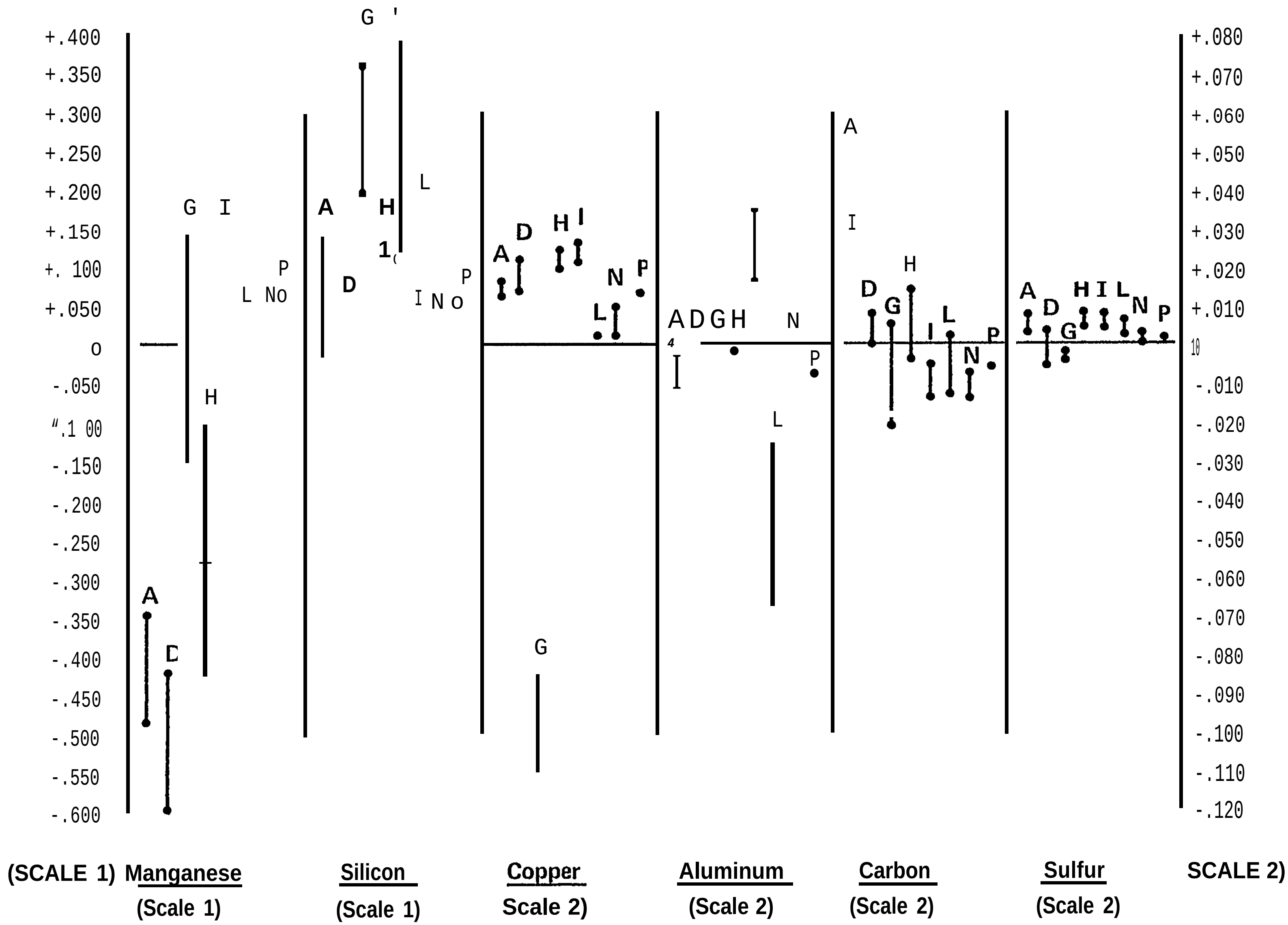
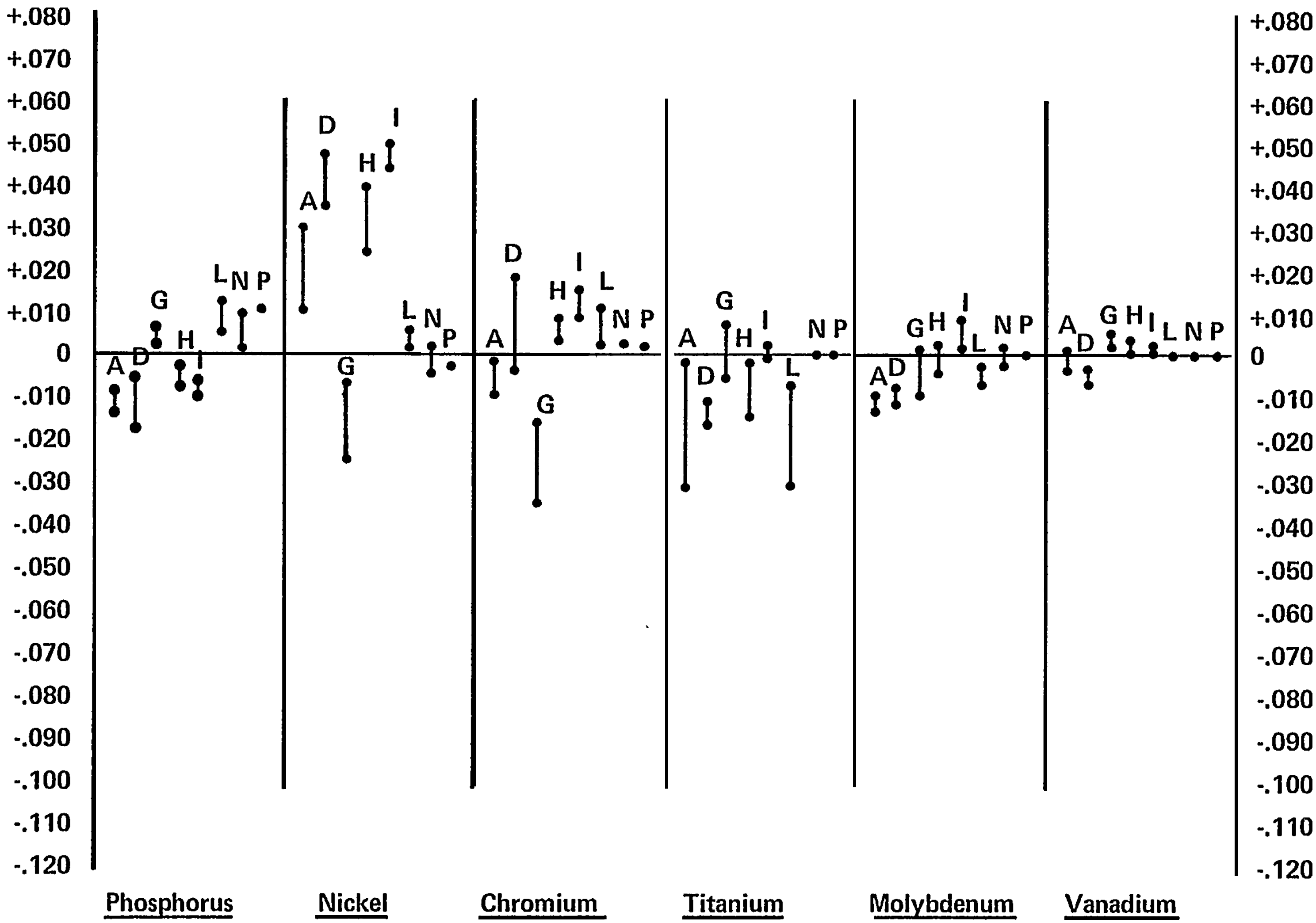


TABLE 6.2

VARIATIONS IN COMPOSITION BETWEEN CERAMIC-BACKED AND CORRESPONDING STEEL-BACKED WELDMENTS



NOTE: For each group except D, the same wire heat was used for the ceramic-backed and corresponding steel-backed weldments.

(CONT)

VI-7 Summary of Analysis

The objective of the evaluation was to determine if ceramic tile backing in flux cored arc welding (FCAW) and submerged arc welding (SAW) applications could provide a second side contour such that back gouging and grinding is not required to prepare the second side for subsequent welding or inspection. Ceramic tile backing was found to provide such a second side contour in FCAW and SAW single wire applications, but in FCAW applications only Phase I (.052" and 1/16" diameter wire with C-25 shielding) did so without significant risk of internal porosity and piping. lower heat input and smaller puddle size combined with the more inert C–25 shielding apparently mitigates the porosity/piping mechanisms described in VI-1. Positioning of the arc toward the center rather than the leading edge of the puddle further decreased the likelihood of porosity and piping but at some expense in second side bead contour. Phase II ($C0_2$ shielded FCAW) and Phase III (self-shielded FCAW) provided good second side bead contour but with a high risk of internal porosity and piping for which consistently reliable corrective measures were not identified. For this reason, Phase II and III type FCAW applications are not recommnended with ceramic tile backing without subsequent volumetric examination.

Acceptable second side contours were consistently obtained with single wire submerged arc. A "finning" phenomenon, apparently depending on a critical relationship of puddle fluidity and ceramic design presented no significant problems with single wire SAW as it did with tandem wire SAW. Minimum puddle fluidity, consistent with adequate penetration and fusion, combined with an appropriate ceramic selection will avoid finning in single wire SAW. Tandem submerged arc, however, apparently due to the inherently larger, more fluid puddle was quite susceptible to finning and as a result is not recommended for use with ceramic tile backing.

Other than finning in tandem SAW applications and porosity piping in certain FCAW applications, no problems of significance were identified in the use of ceramic tile backing. A statistical analysis of Charpy impact data from selected coupons revealed only a very slight difference, if any, in weldment toughness between ceramic-backed and steel-backed weldments and even these differences could possibly be attributed to factors other than ceramic backing. The only other bead shape problems were occasional back bead sag in horizontal Phase I welds, a problem resolved by charges in joint design as discussed in VI-3. The concessions in back bead contour for the purpose of assuring weldment soundness are directly controllable, an acceptable compromise being recommended. Welding stops and starts presented no special problems with FCAW and techniques are recommended in VI-4. Stopping and restarting with SAW, however, is not recommended. The adhesive and magnetic attaching methods both worked satisfactorily. Only reasonable base metal cleanliness is required with the adhesive methods while the magnetic methods are even more forgiving and have the additional advantage of no smoke and odor. Also, the magnetic devices are not temperature sensitive. The ceramic tiles were not found to significantly affect the weld metal chemistry. There were some minor, insignificant variations for ECPW due to increased base metal dilution and sane entrapment of oxidized elements.

The following specific applications are recommended for ceramic tile backing subject to the precautions identified. Problems previously identified with these applications are avoided by following the appropriate precautions. Those applications not recommended, i.e., those applications for which an effective resolution of respective problem areas could not be found, are also identified along with the nature of the problems responsible.

RECOMMENDED

Phase	Group	Specifics	Precautions
I	A	FCAW/E70T-l/. O52° dia./C-25/FLAT	(1) (2) (4)
I	B	ECAW/E70T-l/. O52° dia./C-25 /HOZ.	(1) (2) (3) (4)
I	c	FCAW/E70T-l/. O52° dia./C-25 /VERT.	(1) (2) (4)
I	D	FCAW/E70T-l/l/16° dia./C-25/FLAT	(1) (2) (4)
I	E	FCAW/E70T-l/l/16° dia./C-25/HOZ.	(1) (2) (3) (4)
I	F	ECAW/70T-l/l/16/″ dia.C-25/Vert.	(1) (2) (4)
Iv	M	SAW/EPl12K/l/8° dia./FLAT	(1) (2) (5) (6) (7)
Iv	N	SAW/EM12K/5/32° dia./FLAT	(1) (2) (5) (6) (7)
IV	o	SAW/~12K/3/16° dia./FLAT	(1) (2) (5) (6) (7)

NOTES :

(1) When adhesive attaching methods are used, wiping of contact surfaces with a clean dry cloth just before applying ceramics is minimum cleanliness.

(2) Baking or dry storage may be necessary.

(3) Possibility of back bead sag must be considered in joint design.

(4) Use 30-40° lead angle with arc directed between center and leading edge of puddle to minimize any possibility of piping.

(5) Minimum puddle fluidity consistent with adequate penetration.

(6) Ceramic design should be selected to avoid finning.

(7) Stops and restarts should be avoided.

NOT RECOMMENDED

Phase	Group	Specifics	Reasons
II	G	FCAW/E70T-l/ 5/64″ dia./$C0_2$/FLAT	Frequent Porosity and Piping
II	H	FCAW/E70T-l/ 3/32″ dia./$C0_2$/FLAT	Frequent Porosity and Piping
III	I	FCAW/E70T-G/ 5/64″ dia./FLAT	Frequent Porosity and Piping
III	J	FCAW/E70T-G/ 5/64″ dia./HOZ.	Frequent Porosity and Piping
III	K	FCAW/E70T-G/ 5/64″ dia./VERT.	Frequent Porosity and Piping
III	L	FCAW/E70T-G/ 5/64″ dia./FLAT	Frequent Porosity and Piping
Iv	P	SAW/EM12K/ 5/32″ dia./FLAT/Tandem	Severe Finning

VII . RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Continuation of ceramic backing evaluation with FCAW should center on the resolution of weld soundness, i.e., piping and porosity problems. Such factors as base material thickness and size and/or wire characteristics such as fast-freeze, etc. may have an effect not identified by this evaluation. Variations in welding technique appear promising for resolution of the FCAW soundness problems. An optimum balance must be found between the bead shape advantages of the "broom" effect and avoidance of the soundness problems associated with it. A statistically significant prcgram concentrating primarily on the effects of technique, joint design and welding parameters is necessary to provide a data bank of reliable information for avoidance of the soundness problems.

Continuation of ceramic backing evaluation with single wire SAW should concentrate on determining the optimum combination of welding parameters and ceramic/weld-joint design. The relationship of puddle size and fluidity to the geometry of the ceramic/weld-joint area is important. An appropriately designed evaluation program would identify the limiting factors which will result in an optimum relationship.

The bead shape problems with tandem SAW appear too severe to justify continued evaluation. Tandem SAW, at this point, is not compatible with ceramic backing.

The use of ceramic backing with other processes such as SMAW and GMAW short arc is quite promising. Much information obtained with FCAW and SAW is directly applicable to these two processes. A similar evaluation program would yield beneficial results.

This evaluation program ascertained the technical feasibility of producirgq quality welds with ceramic backing. The primary advantage of ceramic backingis alleged lower cost and/or production time. An in-depth cost/time study for ceramic backing as it relates to other available methcds for performing similar functions would substantiate and quantify these savings.

Although every effort was made to accurately duplicate shipyard conditions, this evaluation was of necessity a laboratory function with small scale test coupons. A planned shipyard evaluation utilizing surface and volumetric examination of production welds may reveal influences of size, fitup, etc., unaccounted for in this evaluation.

APPENDIX A

DETAILED TEST ASSEMBLY PARAMETERS & RESULTS

WIRE TYPE E70T-1/FC707 HEAT 63302225H243 GAS FLOW 40CFH POLARITY DCRP

'EST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1		2		TENSILE	CVN 20°F)					
										P	F	P	F		1	2	3	4	5	AVG.
A-2-1	7	1 2 3 4	260 260 260 260	28 28 28 28	7.5 13.6 13.6 13.6	70 180 350 350	30-40° Lead 30° Trail 30° Trail 30° Trail	String String String String	OK	X		X		U=67,567	38 33 10	39 32 10	50.5 44 20	45 37 20	48 41 20	44.1 37.4 16
A-3-1	6	1 2 3 4	260 260 260 260	28 28 28 28	7.5 13.6 13.6 13.6	70 290 350 350	30-40° Lead 30° Trail 30° Trail 30° Trail	String String String String	OK	X		X		U=66,622	30.5 23 10	39 30 10	42.5 33 15	43 39 20	54 41 30	41.8 33.2 17
!-4-1	6	1 2 3 4	260 260 260 260	28 28 28 28	7.5 13.6 13.6 13.6	70 220 250 350	30-40° Lead 30° Trail 30° Trail 30° Trail	String String String String	OK	X		X		U=67,617	30.5 25 10	40.5 29 10	38 26 10	37 26 15	46 34 20	38.4 28 13
!-5-1	7	1 2 3 4	260 260 260 260	28 28 28 28		70 240 345 350	30-40° Lead 30° Trail 30° Trail 30° Trail	String String String String	OK	X		X		U=65,559	23.5 18 5	34 35 10	29 24 5	30 26 5	26 30 15	28.5 26.6 8
]-1-1	3	1 2 3 4 5 6 7	240 240 240 240 240 240 240	28 28 ;: 28 28 28		70 220 300 310 320 350 NR	15° Lead 15° Lead 15° Lead 15° Lead 15° Lead 15° Lead 15° Lead	String Weave String String String String Weave	OK					U=71,932 Y=48,660	30.5 24 20	18 15 25	20 17 25	22.5 18 30	22.5 18 30	22.7 18.4 26
EI-2-1	8	1	260	26		70	30-400 Lead	String	Excessive Back Bead Saci											
I-2-2	29	1	260	26		70	30-40° Lead	String	FIEJ .	Lack of fusion										
1-2-3	4	1	260	25		70	30-40° Lead	String	IEJ .	Lack of fusion and sag										

1

WIRE TYPE E70T-1/FC707 HEAT 63302225H243 GAS FLOW 40CFH POLARITY DCRP

TEST No.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 4	STRING/ WEAVE	RT	ROOT BENDS 2 P	F	P	F	
B-2-4	4	1	260	26	7.5	70	30-40° Leac	String	REJ					Lack of Fusion
		2	260	26	13.6	180	40° Trail	String						
		3	260	26	13.6	250	40° Trail	String						
		4	260	26	13.6	290	40° Trail	String						
		5	260	26	13.6	350	40° Trail	String						
B-2-5	10	1	280	25	7.5	70	30-40° Leac	String	OK	X		X		
		2	280	25	13.5	150	40° Trail	String						
		3	280	25	13.5		40° Trail	String						
		4	280	25	13.5	290	40° Trail	String						
		5	280	25	13.5	350	40° Trail	String						
B-3-1	4	1	280	25	7.5	70	30-40° Lead	String	REJ					Lack of fusion
B-3-2	4	1	280	25	7.5	70	30-40° Lead	String	REJ					Lack of fusion and saq
B-3-3	4	1	280	25	7.5	70	30-40° Lead	String	OK	X		X		
		2	280	25	13.5	250	40° Trail	String						
		3	280	25	13.5	200	40° Trail	String						
		4	280	25	13.5	325	40° Trail	String						
B-4-1	4	1	280	25	7.5	70	30-40° Lead	String	OK	X		X		
		2	280	25	13.6	150	40° Trail	String						
		3	280	25	13.5	250	40° Trail	String						
		4	280	25	13	340	40° Trail	String						
B-5-1	10	1	280	25	7.5	70	30-40° Lead	String	REJ					Some minor sag at the run-off end. RT rejected for 2″ lack of fusion.
		2	280	25	13.5	160	20° Trail	String						
		3	280	25	13.5	300	20° Trail	String						
		4	280	25	13.5	70	20° Trail	String						
B-5-2	4		260	26	7.5	70	30° Lead	String	*	X		X		* 2″ chevron porosity at start and 1.5″ at center.
		:	260	26	13	125	20° Lead	String						
		3	260	26	13	250	20° Lead	String						
		4	260	26	13	350	20° Lead	String						
		5	260	26	13	345	20° Lead	String						
		6	260	26	13	360	20° Lead	String						

WIRE TYPE E70T-1/FC707 HEAT 63302225H243GAs FLOW 40CFH POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH =	STRING/ WEAVE	RT		ROOT BENDS 2 F	P	F
c-2-1	12	1	220	24	4	70	10-15° Lead	Weave	OK	x		X	
		2	220	24	4	220	15° Trail	Weave					
		3	220	24	4.5.	300	15° Trail	Weave					
c-3-1	13	1	240	24	4	70	20° Lead	Weave	OK	x		X	
		2	240	24	9	125	10° Trail	Weave					
		3	240	24	7	250	10° Trail	Weave					
c-4-1	8	1	240	24	4		20° Lead	Weave	OK	x		X	
		2	240	24	9	125	15° Trail	Weave					
		3	240	24	7	280	15° Trail	Weave					
c-5-1	10	1	240	24	4.5	70	40° Lead	Weave	OK	x		X	
		2	240	24	9	200	30° Trail	Weave					
		3	240	24	8	210	30° Trail	Weave					

WIRE TYPE E70T-1/~ABco-82 H[EAT 32128/1022 GAS FLOW 4OCFII POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT.	TORCH ≤	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F		CVN (20°F) L	CVN (20°F) 2	CVN (20°F) 3	CVN (20°F) 4	CVN (20°F) 5	AVG.
D-2-1			260	36-	8	70	30° Lead	String	OK	x		x		U=67;705	21	21	F	20	21	20.6
	10	1	260	30	7	70	15° Lead	Weave							17	14	13	16	14	14.8
		3	260	30	6.5	195	15° Lead	Weave							10	10	10	10	10	10
		4	260	30	6	300	15° Lead	Weave												
D-3-1	5		260		7.5		60° Lead	String	OK	x		x		J=65,407	39	31f	32	12.5	32	33.4
		:	260	30	7	70	15° Lead	Weave							32	27	23	24	22	25.6
		3	260	30	7	280	15° Lead	Weave							15	10	10	10	10	11
		4	260	30	6	350	15° Lead	Weave												
D-4-1	9	1	260	30	7.5	70	60° Lead	String	OK	x		x		J=64,859	21	Z		30	27	27.2
		2	260		7	160	15° Lead	Weave							16	26	;;	29	20	23.6
		3	260	30	7	290	15° Lead	Weave							5	10	15	15	10	11
		4	260	30	6	350	15° Lead	Weave												
D-5-1	11	1	260	30	7*5	70	60° Lead	String	OK	x		x		J=53,505	20.5	23	18.5	11.5	28	20.3
		2	260	30	7	150	15° Lead	Weave							20	20	20	13	25	19.6
		3	260	30	7	290	15° Lead	Weave							10	10	5	5	10	8
		4	260	30	6	340	15° Lead	Weave												
E-2-1	33	1	260	25	NR	70	30° Lead	String	OK	x		x								
		2	260		NR	280	15° Trail	String												
		3	260	25	NR	290	15° Trail	String												
		4	260	25	NR	330	15" Trail	String												
		5	260	25	NR	350	15° Trail	String												
E-3-1	34	1	260		NR	70	60° Lead	String	OK	x		x								
		2	260	25	NR	260	15" Trail	String												
		3	260	25	NR	295	15° Trail	String												
		4	260	25	NR	325	15° Trail	String												
		5	260	25	NR	350	15° Trail	String												
E-4-1	34	1	260	25	NR	70	60° Lead	Weave	OK	x		x								
		2	260	25	NR	265	15° Trail	Weave												
		3	260	25	NR	295	15° Trail	Weave												
		4	260	25	NR	345	15° Trail	Weave												
		5	260	25	NR	350	15° Trail	Weave												

N E TYPE E70T-1/FABCO-3 IEAT 32128/1022 GAS FLOW 40CFH POLAR TY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F
E-5-1	35	1	260	25	NR	70	30° Lead	String	OK	X		X	
		2	260	25	NR	280	15° Trail	String					
		3	260	25	NR	295	15° Trail	String					
		4	260	25	NR	350	15° Trail	String					
		5	260	25	NR	350	15° Trail	String					

WIRE TYPE E70T-1/FC707 HEAT 1801 GAS FLOW 45CFH POLARITY DCRP

TEST NO.	JOINT	PASS	A	V.	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 1 P	ROOT BENDS 1 F
F-2-1	2		220	22	4	70	NR	Weave	OK	X			
		1	230	22	9	150	NR	Weave					
		3	240	22	7	125	NR	Weave					
		4	240	22	5	150	NR	Weave					
F-3-1	2	1	220	22	6	70	NR	Weave	OK	X		X	
		2	230	22	8.5	90	NR	Weave					
		3	230	22	6	250	NR	Weave					
F-4-1	14	1	230	22	5.25	70	NR	Weave	OK	X		X	
		2	230	22	7.5	125	NR	Weave					
		3	230	22	NR	225	NR	Weave					
F-5-1	1	1	230	22	5.5	70	NR	Weave	OK	X		X	
		2	230	22	7	125	NR	Weave					
		3	230	22	5.6	150	NR	Weave					

WIRE TYPE E70T-1/ FABCO-82 HEAT 282B8 GAS -OW 45CFH FLOW POLARITY

TEST NO.	JOINT	PASS	A	V	(IPM)	INT. (°F)	TORCH 4	STRING/ WEAVE	RT		TENSILL	CVN (20°F) 1	2	3	4	5	AVG.
Q-2-1	3	1	280	27	10.35	70	15° Lead	String	OK		U=74,341	38	32	30.5	30	32	32.5
		2	280	27	7.14	250	15° Trail	Weave			Y=48,266	27	28	26	24	23	25.6
		3	300	28	15	150	15° Trail	String				40	35	35	30	35	35
		4	300	28	12.5	300	15° Trail	String									
		5	300	28	12.5	350	15° Trail	String									
		6	300	28	12.5	350	15° Trail	String									

WIRE TYPE E70T-1/FABCO-82 HEAT 18122K8 GAS FLOW 40CFH POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	TENSILE	CVN (20°F) 1	2	3	4	5	AVG.
G-1-1	6	1 2 3	430 430 430	31 31 31	NR NR NR	70 150 350	30° Lead 70° Lead 70° Lead	String String Slight Weave	OK	X		X		U=65,285 Y=30,560	17 10 10	17 8 5	16 11 5	13 9 10	13 6 5	15.2 8.8 6.4
G-2-1	10	1	410	31	NR	70	30° Lead	String	Approximately 2" rough area on underbead											
G-2-2	5	1 2 3	390 390 390	31 31 31	NR NR NR	70 190 320	30° Lead 45° Lead 45° Lead	String String String	OK	X		X		U=65,007 Y=43,243	80.5 61 60	12 13 10	10.5 14 10	11.5 13.5 10	10 9 10	24.9 22.1 20
G-3-1	20	1 2 3 4	280 280 280 280	28 28 28 28	NR NR NR NR	70 185 280 350	30° Lead 70° Lead 70° Lead 70° Lead	String Weave Weave Weave	REJ	Approximately 3.5" of Chevron Porosity										
G-3-2	5	1 2 3	360 360 360	27 27 27	8.5 9 9	70 190 240	30° Lead 50° Lead 50° Lead	String Weave Weave	OK	X		X		U=65,593 Y=42,606	16.5 18 15	12.5 14 10	10 12 10	8.5 8 5	10 11 10	11.5 12.6 10
Q-3-1	3	1 2 3 4 5 6	320 320 320 320 320 320	28 28 28 28 28 28	11.5 10.7 15 15 15.5 15	70 300 290 350 180 300	15° Trail 15° Trail 15° Trail 15° Trail 15° Trail 15° Trail	String Weave String String String String	OK					U=74,270 Y=48,957	18 18 25	27.5 22 30	24.5 23 20	20.5 19 20	29.5 26 25	24 21.6 24

WIRE TYPE E70T-1/FABCO-82 HEAT 4302L8 GAS FLOW 45 CFH POLARITY DCRP

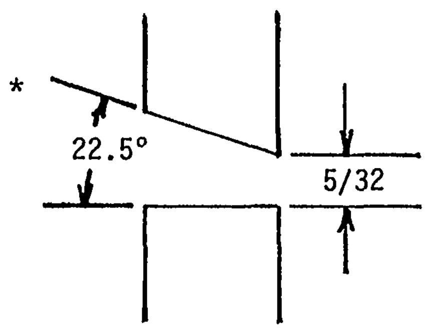
TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	TENSILE	CVN (20°F) 1	CVN 2	CVN 3	CVN 4	CVN 5	CVN AVG.
H-1-1	5 5	1 2 3	400 400 400	28 28 28	7.5 12 10	70 230 320	30° Lead 15° Lead 15° Lead	String String Weave	Chevron porosity and surface porosity											
H-1-2	5	1 2 3	400 400 400	28 28 28	7.5 12 10	70 160 300	30° Lead 15° Lead 15° Lead	String String Weave	Chevron porosity and surface porosity											
H-2-1	5	1 2 3	400 400 400	28 28 28	8 12 10	70 250 300	30° Lead 15° Lead 15° Lead	String String Weave	Chevron porosity and surface porosity											
H-2-2	5	1 2 3	400 400 400	28 28 28	8 12 12	70 110 110	30° Lead 15° Lead 15° Lead	String String String	Chevron porosity and surface porosity											
H-1-3	15	1 2 3 4	400 400 400 400	28 28 28 28	8.5 11.75 15 13	70 220 300 350	30° Lead 15° Lead 15° Lead 15° Lead	String String Weave Weave	OK	X		X		U=70,914 Y=45,429	15.5 14 10	14.5 13 10	20 18 15	16.5 16.5 10	16 15 15	16.5 15.3 12
H-2-3	16	1 2 3	400 400 400	28 28 28	9 12 7	70 130 270	30° Lead 15° Lead 15° Lead	String String Weave	OK	X			X	U=70,200 Y=44,269	16.5 16.5 10	19 21.5 10	14.5 14 10	15.5 14 10	11.5 14.5 10	15.4 16.1 10
H-3-1	15	1 2 3	400 400 400	28 28 28	10 12 7.25	70 250 150	30° Lead 15° Lead 15° Lead	String String Weave	OK	X		X		U=70,707 Y=47,330	13.5 13.5 10	14 12 10	14.5 15 10	17.5 19 10	13.5 16 10	14.6 15.1 10
Q-4-1	17	1 2 3 4 5	400 400 400 400 400	28 28 28 28 28	13 7.75 8 12 12	70 200 250 300 350	15° Lead 15° Lead 15° Lead 15° Lead 15° Lead	String Weave Weave Weave Weave	OK					U=72,546 Y=50,071	26.5 25 25	28 28.5 30	25.5 25 20	30 26 20	24 32 25	26.8 27.3 24

WIRE TYPE E70T-G/NR203M HEAT BB830 POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	1 F	2 P	2 F	TENSILE	CVN (20°F) 1	2	3	4	5	AVG.
I-2-1	18	1	300	20	7	70	45° Lead	String	Rej	Chevron porosity and piping										
		2	300	20	7	240	20° Lead	Weave												
		3	300	20	7	290	20° Lead	Weave												
		4	300	20	7	350	20° Lead	Weave												
I-2-2	18	1	340	20	7	70	20° Lead	String	OK	X		X		U=67,669	41	76	114	61	83	75
		2	340	20	7	245	20° Lead	Weave						Y=30,880	35	53	64	44	52	49.6
		3	340	20	7	300	20° Lead	Weave							20	25	45	20	30	28
		4	340	20	7	350	20° Lead	Weave												
I-3-1	19	1	300	20	7	70	NR	String	Excessive back bead build up											
		2	300	20	7	150	NR	Weave												
I-3-2	19	1	340	20	7	70	NR	String	OK	X		X		U=67,359	56	61	52	46	78	58.6
		2	340	20	7	230	NR	Weave						Y=32,800	44	45	43	43	47	44.4
		3	340	20	7	320	NR	Weave							15	25	15	30	40	25
		4	340	20	7	350	NR	Weave												
I-4-1	19	1	340	20	7	70	45° Lead	String	Rej.	Lack of fusion										
I-4-2	20	1	340	20	7	70	45° Lead	String	OK	X		X		U=67,514	60	22.5	44	31	54	42.3
		2	340	20	7	230	45° Lead	Weave						Y=31,680	43	25	32	26	36	32.4
		3	340	20	7	70	45° Lead	Weave							10	5	15	5	15	10
		4	340	20	7	240	45° Lead	Weave												
		5	340	20	7	350	45° Lead	Weave												
I-5-1	19	1	340	20	7	70	45° Lead	String	OK	X		X		U=66,622	80.5	57	72.5	84	66.5	72.1
		2	340	20	7	160	45° Lead	Weave						Y=44,043	60	50	62	58	46	55.2
		3	340	20	7	250	45° Lead	Weave							30	10	30	35	30	27
		4	340	20	7	350	45° Lead	Weave												

WIRE TYPE E70T-G/NR203M HEAT B8B820 POLARITY DCSP

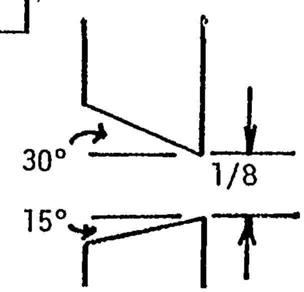
TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	
J-2-1	*	1	300	22	NR	70	40° Lead	String	Rej.					Piping
		2	300	22	NR	135	20° Lead	String						
		3	300	22	NR	200	20° Lead	String						
		4	300	22	NR	280	20° Lead	String						
		5	300	22	NR	150	20° Lead	String						
		6	300	22	NR	210	20° Lead	String						
J-3-1	4	1	220	20	NR		40° Lead	String	OK	X		X		
		2	220	20	NR		20° Lead	String						
		3	220	20	NR		20° Lead	String						
		4	220	20	NR		20° Lead	String						
		5	220	20	NR		20° Lead	String						
		6	220	20	NR		20° Lead	String						
J-4-1	10	1	220	20	NR	70	50° Lead	String	Rej.					Approximately 11" chevron porosity and piping
		2	220	20	NR	95	5° Lead	String						
		3	220	20	NR	210	5° Lead	String						
		4	220	20	NR	240	5° Lead	String						
		5	220	20	NR	300	5° Lead	String						



WIRE TYPE E70T-G/NR203M HEAT BB830 POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 1 P	ROOT BENDS 1 F
J-2-2	*	1	230	22		70		String	Gross porosity				
J-2-3	15	1	250	20		70	40° Lead	String	OK	X		X	
		2	250	20		150	20° Lead	String					
		3	250	20		200	20° Lead	String					
		4	250	20		325	20° Lead	String					
		5	250	20		350	20° Lead	String					
		6	250	20		300	20° Lead	String					
J-4-2	15	1	250	20	5.25	70	40° Lead	String	OK	X		X	
		2	250	20	15	110	20° Lead	String					
		3	250	20	13	230	20° Lead	String					
		4	250	20	17	250	20° Lead	String					
		5	250	20	15	300	20° Lead	String					
		6	250	20	12.5	350	20° Lead	String					
J-5-1	15	1	250	20	4.5	70	40° Lead	String	Rej.	Piping			
		2	250	20	15.5	250	20° Lead	String					
		3	250	20	6.52	300	20° Lead	String					
		4	250	20	12	200	20° Lead	String					
		5	250	20	13	275	20° Lead	String					
		6	250	20	11.5	350	20° Lead	String					
J-5-2	13	1			5.65	70	40° Lead	String	Rej.	Piping			
J-5-3	15	1	250	20	5.8	70	40° Lead	String	OK	X		X	
		2	250	20	13	70	20° Lead	String					
		3	250	20	9.5	200	20° Lead	String					
		4	250	20	11.5	300	20° Lead	String					
		5	250	20	17	350	20° Lead	String					
		6	250	20	10	350	20° Lead	String					

*



WIRE TYPE E70T-G/NR203M HEAT 622J POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 1 P	ROOT BENDS 1 F
K-2-1	30	1 2 3	240 240 240	19 19 19	4 5 6.12	70 100 200	45° Lead 15° Trail	Weave Weave Weave	OK	X		X	
K-3-1	2	1	240	19	4	70	45° Lead	Weave	Excessive burn through				
K-3-2	31	1 2 3	240 240 240	19 19 19	4.5 6 3.5	70 230 130	45° Lead 15° Trail 15° Trail	Weave Weave Weave	OK	X		X	
K-4-1	31	1 2 3	240 240 240	19 19 19	4 5 4	70 100 240	45° Lead 15° Trail 15° Trail	Weave Weave Weave	OK	X		X	

WIRE TYPE E70T-G/NR203M HEAT 622J POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F
K-5-1	32	1 2 3	240 240 240	19 19 19	4.5 5 3.5	70 100 250	45° Lead 15° Trail 15° Trail	Weave Weave Weave	OK	X		X	

WIRE TYPE E70T-G/NR302 HEAT EKCF721 POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	
L-2-1	16	1 2 3	400 400 400	28 28 28	12 9 8.5	70 135 200	45° Lead 15° Lead 15° Lead	String String Weave	Rej.	Gross chevron porosity and piping

WIRE TYPE E70T-G/NR302 HEAT EKCF721 POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	1 F	2 P	2 F	TENSILE	CVN (20°F) 1	2	3	4	5	AVG
L-2-2	16	1	400	28	12	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-2-3	13	1 2 3 4	400 400 400 400	28 28 28 28	11.65 12.72 13.33 13.33	70 70 300 350	45° Lead 15° Lead 15° Lead 15° Lead	String String String String	OK	X		X		U=71,866 Y=48,746	62 52 60	55 52 45	70 59 50	80 64 65	65.5 56 55	66.5 56.6 55
L-3-1	16	1	400	28	13	70	45° Lead	String	REJ.	Chevron porosity and piping in first half of plate.										
L-3-2	13	1 2 3	400 400 400	28 28 28	13.10 12 7.75	70 70 230	45° Lead 15° Lead 15° Lead	String String Weave	OK	X		X		U=71,332 Y=45,652	69 62 50	49 47 30	68.5 61 65	70.5 58 65	61.5 55 55	63.7 56.6 53
L-4-1	16	1	400	28	13.33	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-4-2	16	1 2 3	400 400 400	28 28 28	13.3 9.5 8.63	70 70 300	45° Lead 15° Lead 15° Lead	String String Weave	OK	X			X	U=70,518 Y=45,684	57 44 40	70 55 65	60 49 50	39 37 25	43.5 38 35	53.9 44.6 43
L-5-1	16	1	400	28	13.6	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-5-2	16	1 2 3	400 400 400	28 28 28	13.5 10 7.25	70 70 330	45° Lead 15° Lead 15° Lead	String String Weave	OK	X		X		BROKE IN WELD U=58,060 Y=48,770	69 62 60	84 72 70	66 57 50	87.5 72 75	67 63 50	74.7 65.2 61
R-2-1	21	1 2 3 4	400 400 400 400	28 28 28 28	9.3 8.16 10 10	70 250 350 350	15° Lead 15° Lead 15° Lead 15° Lead	String Weave String String	OK					U=72,650 Y=50,997	38 40 40	64 56 50	59 50 40	70 57 50	65.5 55 60	59.3 51.6 48

WIRE TYPE E70T-G/NR203M HEAT BB830 POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (^oF)	TORCH ∠	STRING/ WEAVE	RT		TENSILE	CVN (20^oF) 1	2	3	4	5	AVG
R-1-1		1	250	20	10	70	15° Lead	String	OK			65.5	73	73	92	78.5	76.4
	3	2	250	20	11.5	210	15° Lead	String				55	45	60	66	64	58
		3	250	20	10	260	15° Lead	String			U=72,263	60	45	65	75	70	63
		4	250	20	10	350	15° Lead	String									
		5	250	20	10.5	300	15° Lead	String			Y=46,715						
		6	250	20	10	350	15° Lead	String									
		7	250	20	12	250	15° Lead	String									
		8	250	20	10	350	15° Lead	String									
		9	250	20	NR	350	15° Lead	String									

WIRE TYPE EM12K/LINDE-81 HEAT 081205 POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (^{o}F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F
M-1-1	22	1 2	640 500	34 38	10 10	70 70	0° 0°	String String	OK	X		X	
M-2-1	23	1 2	640 500	34 36	10 10	70 150	0° 0°	String String	OK	X		X	
M-3-1	22	1 2	650 450	34 35	9.5 10	70 70	0° 0°	String String	OK	X		X	

WIRE TYPE EM12K/LINDE-81 HEAT 081206 POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	TENSILE	CVN (20°F) 1	CVN (20°F) 2	CVN (20°F) 3	CVN (20°F) 4	CVN (20°F) 5	CVN (20°F) AVG
N-1-1	23	1	750	34	9.5	70	0°	String	OK	X		X		U=68,619 Y=45,077	20 21 5	22 23 5	26.5 28.5 5	24.5 28.5 5	21.5 24.5 5	22.9 25.1 5
N-2-2	23	1	750	34	9.5	70	0°	String	OK	X		X		BROKE IN WELD U=68,516 Y=45,076	20.5 21 5	25 26 5	19.5 21 5	23.5 24.5 5	29 30 5	23.5 24.5 5
N-3-1	23	1 2	750 640	34 38	9.5 10	70 140	0° 0°	String String	OK	X		X		U=68,486 Y=46,494	10.5 15 10	15.5 22 15	17.5 20 10	22 24 .5	19 25 10	16.9 21.2 12
S-1-1	24	1 2 3	750 750 750	38 38 38	10.5 10.5 10.5	70 150 220	0° 0° 0°	String String String	OK					U=66,950 Y=43,120	19 18.5 5	14 18 5	19.5 21.5 5	21 25 5	18.5 23 5	18.4 21.2 5

WIRE TYPE EM12K/LINDE-81 HEAT 081168 POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	
0-1-1	27	1 2	820 800	34 40	11 15	70 200	0° 0°	String String	OK	X		X		
0-2-1	25	1	820	33	11	70	0°	String	Finning occurred beginning at 8" and continuing to 30" along length of weld					
0-2-2	28	1 2	820 760	33 40	11 15	70 190	0° 0°	String String	OK	X			X	0-2-2 root bend had one open defect greater than 1/8"
0-3-1	29	1	820	33	11	70	0°	String	Finning					
0-3-2	29	1 2	850 750	34 40	10.5 15	70 200	0° 0°	String String	OK	X		X		

WIRE TYPE EM12K/LINDE-81 HEAT 081206 POLARITY DCRP (Lead)/AC (Trail) DC/AC

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH ∠	STRING/ WEAVE	
P-1-1	25	1	750/ 600	32/ 40	13	70	15° 0°	String	Reentry angle too small (too sharp)
P-1-2	25	1	750/ 600	32/ 40	15	70	15° 0°	String	Reentry angle too small (too sharp)
P-1-3	25	1	750/ 600	32/ 39	11	70	15° 0°	String	Back bead very ropey and thick
P-1-4	23	1	750/ 600	32/ 40	15	70	15° 0°	String	Very high back bead
P-2-1	23	1	750/ 600	32/ 39	11	70	15° 0°	String	Excessive back bead reinforcement and ropey appearance. Reentry angle too small (too sharp).
P-2-2	23	1	750/ 600	32/ 39	13	70	15° 0°	String	Narrow back bead. Reentry angle too small (too sharp)
P-2-3	23	1	750/ 600	32/ 40	15	70	15° 0°	String	Finning
P-2-4	23	1	750/ 600	32/ 40	15	70	15° 0°	String	Reentry angle too small (too sharp). Finning
P-2-5	23	1	750/ 600	32/ 39	10	70	15° 0°	String	Finning
P-2-6	25	1 2	750/ 600 750/ 600	32/ 40 32/ 40	17 16	70 70	15° 0°	String String	Narrow back bead and finning
P-3-1	23	1	750/ 600	32/ 38	18	70	15° 0°	String	Lack of back side penetration.
P-3-2	25	1	750/ 600	32/ 38	18	70	15° 0°	String	Finning

WIRE TYPE EM12K/LINDE-81 HEAT 081206 POLARITY DCRP (Lead)/AC (Trail) DC/AC

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS 1 P	ROOT BENDS 1 F	ROOT BENDS 2 P	ROOT BENDS 2 F	TENSILE	CVN (20°F) 1	CVN 2	CVN 3	CVN 4	CVN 5	CVN AVG.
P-3-3	25	1	830/ 600	32/ 38	15	70	15° 0°	String	Finning											
P-3-4	25	1	750/ 600	32/ 39	15	70	15° 0°	String	Excessive Back Bead Burn Up											
P-3-5	25	1	750/ 600	32/ 40	14	70	15° 0°	String	OK	X		X		U=68,741 Y=45,643	13.2 26 5	21 28 5	16.5 16 5	21 24.5 5	17.5 20 7.5	17.9 22.9 5
T-1-1	26	1	740/ 620	33/ 40	25	70	15° 0°	String						BROKE IN WELD U=68,393 Y=45,032						
		2	740/ 620	33/ 40	25	180		String												
		3	740/ 620	33/ 40	23	190		String												
		4	740/ 620	33/ 40	21	260		String												

GE

GENERAL R E

SHIP DESIGN IM

AUTOKON '71 . SHIP Pr

COMPUTER AIDS TO SHIPI

SHIP DESIGN IMPROVEM

WELDING PROGRAM I

SURFACE PREPARATION A

SHIP DESIGN IM

COMPUTER All

MATERIALS H1

WI